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RESEARCH ON VISUAL DISPLAY INTEGRATION FOR ADVANCED FIGHTER AIR--ETC(U)

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## RESEARCH ON VIRTUAL DISPLAY INTEGRATION FOR ADVANCED FIGHTER AIRCRAFT

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**COUNTER AIR**
  
2. The subtitle of Figure 27 (pp 58-61) should be relabeled as:  
**CLOSE AIR SUPPORT**

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) <i>This "Visual Display Integration" study was conducted to determine the display integration options projected as available for inclusion in an attack/fighter aircraft crew station design in the 1985-1990 time. A second objective was the definition of an evaluation framework that would permit evaluation of the selected display options during future related studies.</i>		
<i>Summarizing the results, it is clearly evident that the CRT, as Option 1, will retain its preeminence as the multifunction display unit for 1985-1990. Option 2 is the flat-panel plasma display, Option 3 is the flat-panel</i> <span style="float: right;"><i>From mt</i></span>		

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20. ABSTRACT - Continued

liquid crystal display, and Option 4 is the electroluminescent thin-film-transistor display. It was concluded that man-in-the loop simulations provide the best opportunity for evaluating these display options in future related work.

The rapid development of on-board computational capability has provided the aircraft crew station designer with the opportunity to present pilot information in varied quantities and formats. Increased complexity of the projected missions, weapons delivery and aircraft systems has prompted a strong effort to provide better information and control to the weapons system managers (the flight crews) via a fully integrated cockpit. The selection and implementation of the display system is fundamental to the realization of this important goal: a fully integrated crew station that provides low-workload, efficient control of the weapons system, thereby enhancing the probability of mission success and survival.

## PREFACE

This report is a descriptive summary of the work performed by McDonnell Aircraft Company on a study entitled "Research on Visual Display Integration for Advanced Fighter Aircraft" under Air Force Contract F33615-77-C-0536 for the Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Dayton, Ohio. The study was conducted by the advanced crew station design group assigned to Advanced Design Engineering with MCAIR.

The authors acknowledge the excellent guidance of P. V. Kulwicki, AMRL Program Manager, in supporting the MCAIR Study Team with sage advice and pertinent information. The study is considered very important to, and timely for, the development of an integrated display system for advanced fighter aircraft. The advent of mini-computers which control multi-function displays to provide flight crews with a variety of selectable information, has brought to a close the era of dedicated instruments providing only a single bit of information to the crew. Recognizing the importance and magnitude of the display integration task is a significant step toward attaining a fully integrated cockpit for the combat aircraft of the 1980's.

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LIST OF SYMBOLS AND ABBREVIATIONS

A/A	Air-to-Air
A/C	Aircraft
A/S	Air-to-Surface
AAA	Anti-Aircraft Artillery
AAR	Air-to-Air Refueling
AC	Aircraft Commander
ADC	Air Data Computer
ADF	Automatic Direction Finding
AF	Air Force
AFTI	Advanced Fighter Technology Integrator
AI	Air Interdiction
AIDS	Advanced Integrated Display System
AIMIS	Advanced Integrated Modular Instrumentation System
Ambience	Surrounding or Pervading Atmosphere
AMD	Aerospace Medical Division
AMRAAM	Advanced Medium Range Air-to-Air Missile
AMRL	Aerospace Medical Research Laboratory
ANC	Alphanumeric Character
AOA	Angel of Attack
ATF	Advanced Tactical Fighter
ATS	Air-to-Surface Technology Study
AWACS	Airborne Warning and Control System
BCIU	Bus Control Interface Unit
BLU	Bomb Live Unit
C <sup>3</sup>	Command, Control, and Communication

LIST OF SYMBOLS AND ABBREVIATIONS (Continued)

C/D	Controls and Displays
CA	Counter Air
CADM	Cluster Airfield Defeat Munitions
CAS	Close Air Support
CDC	Control Data Corporation
CDRL	Contract Data Requirement List
CET	Central European Theater
COM	Communication
Corr	Correlation
CRT	Cathode Ray Tube
DAIS	Digital Avionics Information System
DED	Dedicated Displays
DFCS	Digital Flight Control System
DME	Distance Measuring Equipment
EC	Electrochromics
ECM	Electronic Countermeasures
EL	Electroluminescence
EO	Electro Optical
EP	Electrophoretics
epi	Elements per inch
EPID	Electrophoretic Image Displays
FAC	Forward Air Controller
fcd	foot candles
FEBA	Forward Edge of Battle Area
FLIR	Forward Looking Infrared

LIST OF SYMBOLS AND ABBREVIATIONS (Continued)

FLR	Forward Looking Radar
FPM	Feet Per Minute
FPS	Feet Per Second
FRAG	Fragmentary
ftl	foot lambert
GPH	Gallons Per Hour
GPS	Global Positioning Satellite
GS	Ground Speed
h	hours
HAC	High Acceleration Cockpit
HMD	Helmet Mounted Display
HSD	Horizontal Situation Display
HSM	Hard Structure Munition
HUD	Head-Up Display
IAS	Indicated Airspeed
IFF	Identification Friend or Foe
IIR	Imaging Infrared
ILS	Instrument Landing System
IMFK	Integrated Multifunction Keyboard
in	inch
INS	Inertial Navigation System
IR	Infrared
IRAD	Independent Research and Development
ITT	International Telephone and Telegraph
JCS	Joint Chiefs of Staff

LIST OF SYMBOLS AND ABBREVIATIONS (Continued)

JTIDS	Joint Tactical Information Distribution System
K	1000
Kh	Kilohours
l/w	lumens per watt
Lambertian	diffuse, or a radiator that has constant radiance in all directions from its surface
LB	pounds
LBM	pounds mass
LC	Liquid Crystal
LCD	Liquid Crystal Display
LD	Laser Displays
LED	Light Emitting Diode
LOAL	Lock-On After Launch
LOBL	Lock-On Before Launch
LORAN	Long-Range Navigation
LRA	Long-Range Attack
LRU	Line Replaceable Unit
LSI	Large Scale Integration
$\mu$ W	Microwatts
MCAIR	McDonnell Aircraft Company
MCG	Microwave Command Guidance
MHz	MegaHertz
MK	Mark
MMD	Multimode Display
MPD	Multipurpose Display, or Magnetic Particles Display
MPH	Miles Per Hour

**LIST OF SYMBOLS AND ABBREVIATIONS (Continued)**

ms	millisecond
MSI	Medium Scale Integration
MTBF	Mean Time Between Failures
mw	milliwatts
Nematic	One of three classes of mesomorphic behavior exhibited by liquid crystals with each class characterized by a specific molecular arrangement
NM	Nautical Miles
NMPH	Nautical Miles Per Hour
PAL	Permissive Action Link
PLD	Plasma Devices
POL	Petroleum, Oil, Lubricant
PPH	Pounds Per Hour
R&D	Research and Development
RAC	Radiometric Area Correlator
RH	Relative Humidity
RHAWS	Radar Homing and Warning System
ROE	Rules of Engagement
RPM	Revolutions per Minute
RTU	Remote Terminal Unit
SAM	Surface-to-Air Missile
SAR	Synthetic Aperture Radar
SID	Society for Information Display
SMS	Stores Management System
SPD	Stereo-Optic Panoramic Display
SRA	Short Range Attack

LIST OF SYMBOLS AND ABBREVIATIONS (Continued)

SRS	Stores Release System
TAC	Tactical Air Command
TACAIR	Tactical Air Power
TACAN	Tactical Air Navigation
TACS	Tactical Air Control System
TAS	True Airspeed
TDMA	Time Division Multiple Access
TERCOM	Terrain Contour Matching
TFEL	Thin Film Electroluminescence
TFR	Terrain Following Radar
TFT	Thin Film Transistor
TV	Television
UHF	Ultra High Frequency
USAF	United States Air Force
VAC	Volts Alternating Current
VAS	Voice Actuated Systems
VSD	Vertical Situation Display
W	Watts
waam	Wide Area Anti-Armor Munition
WPAFB	Wright-Patterson Air Force Base

## 1. INTRODUCTION

Presented herein are the results of the study, "Research on Visual Display Integration for Advanced Fighter Aircraft," conducted by McDonnell Aircraft Company for the Aerospace Medical Research Laboratories under Contract Number F33615-77-C-0536 dated 13 July 1977.

The anti-air defenses estimated to counter future attack/fighter systems will necessitate the employment of maximum skill by the combat aircrews using the most advanced equipment to both accomplish their mission and to survive. The quality of information presented to the crews and the method by which it is presented are considered the most important elements in the design of a highly-effective combat crew station.

This study has explored the mission requirements, aircrew functions, current and projected weapons, crew information requirements and display technologies applicable to the 1985-1990 attack/fighter mission. A major objective of the study was to identify display integration options available for the 1985-1990 crew station.

The study consisted of four major tasks: (1) survey and analysis to establish data base, (2) definition and analysis of crew requirements, (3) identify display integration options, and (4) develop planning for evaluation framework. Section 2 presents a summary of the principal results, conclusions and recommendations. Sections 3 through 6 of this report identify study results pertinent to each of the major tasks. Conclusions are summarized in Section 7 and the recommendations are made in Section 8. The report is presented in a task-oriented format.

Selected display integration options are defined in Section 5. The technical information and rationale used in determining Options 1, 2, 3 and 4 are presented therein.

Information that should be considered in defining future related work, evaluation of the selected display integration options defined herein, is presented in Section 6. This task involved a review of available evaluation techniques and the identification of the technique considered the most appropriate for the follow-on study.

## 2. SUMMARY

The four major tasks, and their interaction, are illustrated in Figure 1. Figure 2, the Program Schedule, relates these tasks to time. A summary of each major task follows.

Task 1 established the data base required to conduct the study and was composed of the following seven subtasks: establishment of the study ground rules, identification of mission profiles, generation of mission requirements, identification of the weapons projected as available in 1985-1990, determination of the aircrew complement, definition of aircrew functions, and a survey of technology options.

Task 2 defined the crew requirements and crew information requirements necessary for mission accomplishment. Typical profiles were developed for Close Air Support, Air Interdiction and Counter Air missions. Mission requirements were generated for each phase of flight in each type of mission. Air crew functions were divided into the two categories of "Mission" and "housekeeping."

In Task 3 the promising approaches to display integration were identified by surveying the avionics field for display methods that show promise and availability for the 1985-1990 time period. The most promising display options were selected for their capability, maturity, availability, and projected cost and reliability.

The output of Task 4 is the development of a planning framework for evaluating candidate display alternatives and comparing competing display alternatives during a follow-on study. It was determined that manned combat simulations would provide the best evaluation technique. An example of a typical simulation activity, involving recommended procedures for evaluating the display options, was prepared and is included in Section 6 of this report.

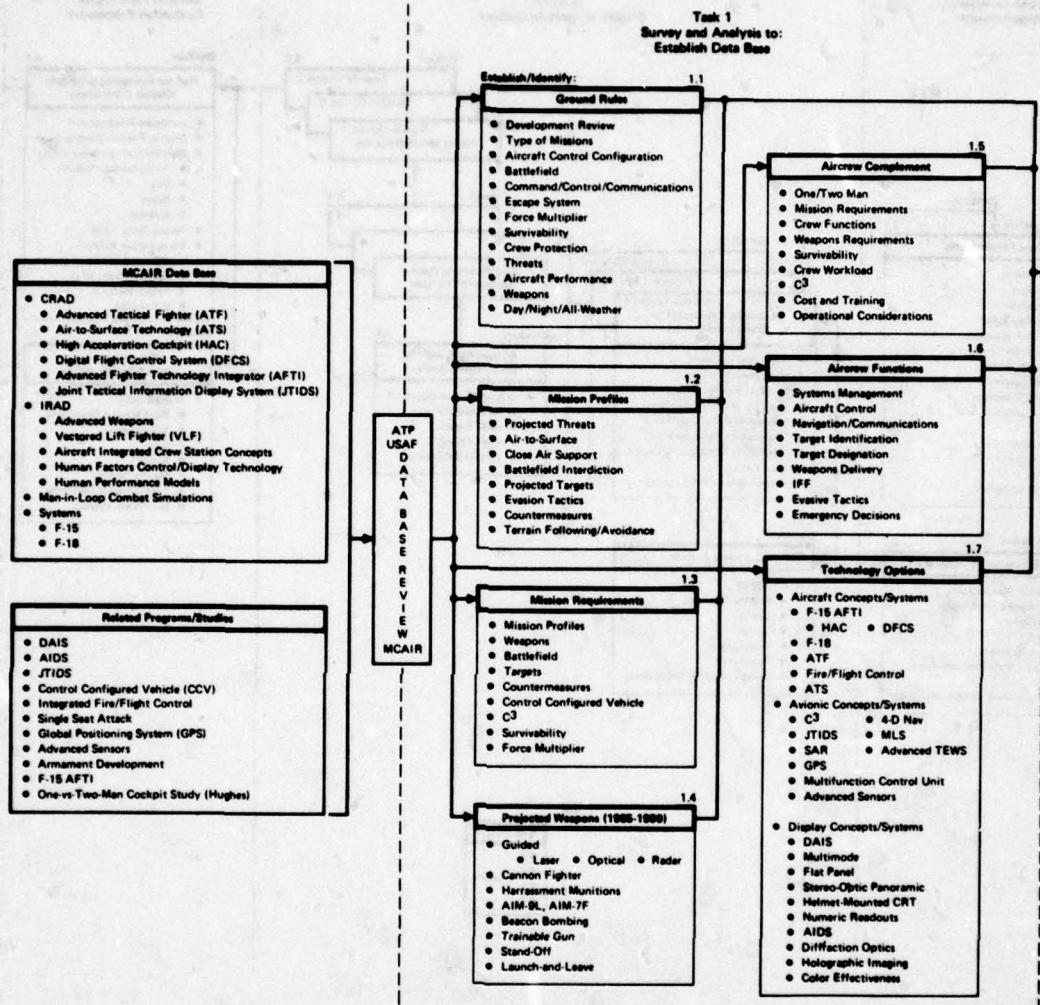
### RESULTS:

(1) Profiles and phases of flight were generated for Close Air Support (CAS), Air Interdiction (AI), and Counter Air (CA) missions utilizing the Central European theater as the battlefield. They are presented in Appendix A.

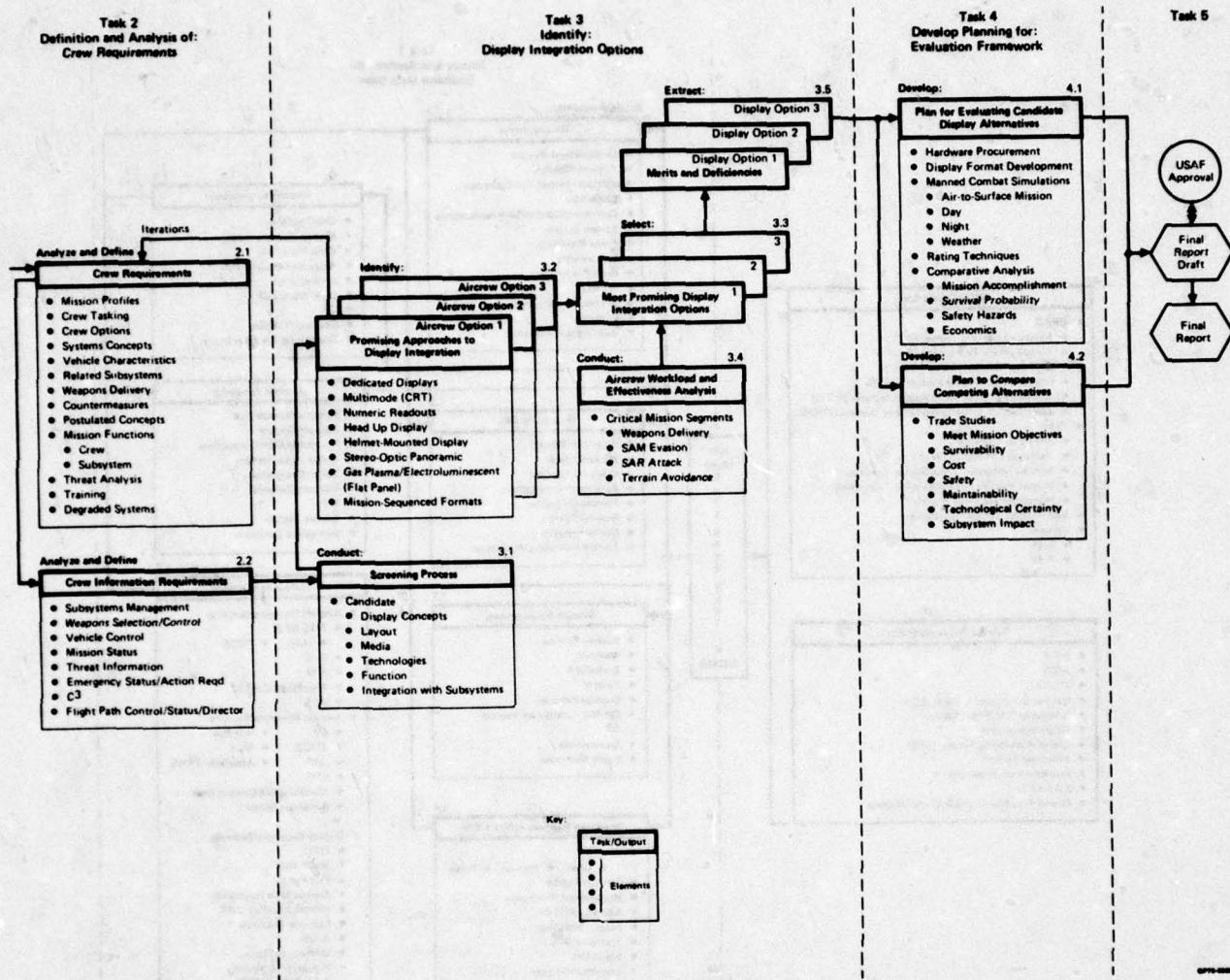
(2) Mission requirements were generated for each phase of the CAS, AI and CA missions and are presented in Appendix B.

(3) Crew Information Requirements were developed for pre-flight, in-flight and post-flight phases of the CAS, AI and CA missions and are presented in Section 4.

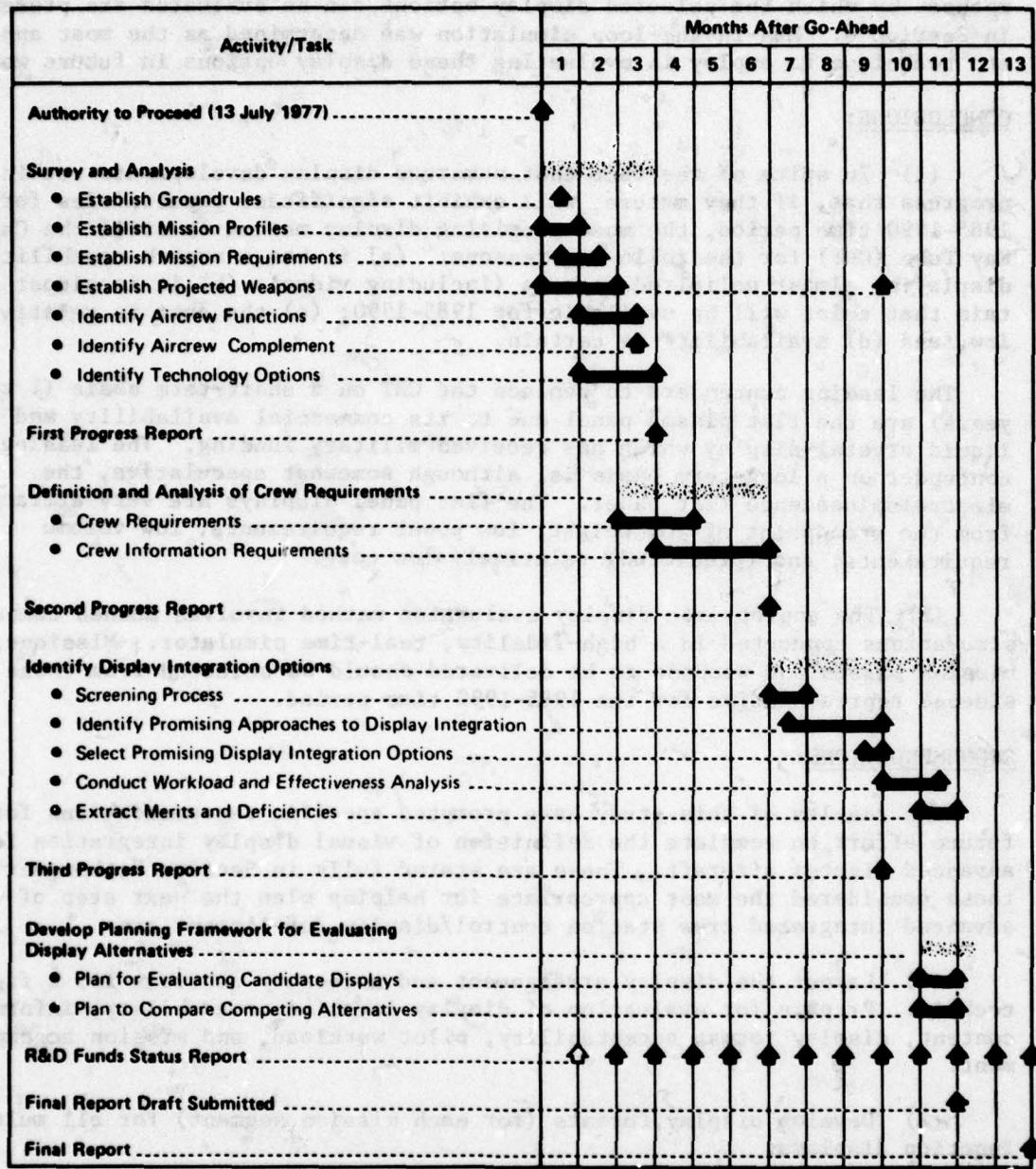
(4) Available/projected display technologies were summarized from an advanced technology survey and are presented in Section 5 along with the selected three display integration options. The Cathode Ray Tube, Option 1, is projected to retain its preeminence as the multipurpose display for the 1985-1990 attack/fighter crew station.



**Figure 1**  
**Program Task Flow**



**Figure 1 (Concluded)**  
**Program Task Flow**



**Figure 2**  
**Program Schedule**

(5) The display evaluation framework was synthesized and available methods by which the selected display options can be evaluated are presented in Section 6. Man-in-the-loop simulation was determined as the most appropriate technique to employ in evaluating these display options in future work.

CONCLUSIONS:

(1) In spite of the fact that numerous display developments are in progress that, if they mature, will exhibit significant capabilities for the 1985-1990 time period, the most promising display method is still the Cathode Ray Tube (CRT) for the following reasons: (a) it has a superb capability for displaying almost unlimited formats (including video); (b) it is almost certain that color will be available for 1985-1990; (c) the cost is relatively low, and (d) availability is certain.

The leading contenders to replace the CRT on a short-term basis (1 to 5 years) are the flat plasma panel due to its commercial availability and the liquid crystal display which has received military funding. The leading contender on a long-term basis is, although somewhat speculative, the electroluminescence flat panel. The flat panel displays are very attractive from the standpoint of low weight, low power requirements, low volume requirements, and (predicted) relatively low cost.

(2) The appropriate display evaluation method involves manned combat simulations conducted in a high-fidelity, real-time simulator. Missions, mission phases and weapons to be delivered should be selected from those considered representative for the 1985-1990 time period.

RECOMMENDATIONS:

The results of this study have prompted specific recommendations for future effort to complete the definition of visual display integration for advanced fighter aircraft. These are stated fully in Section 8; however, those considered the most appropriate for helping plan the next step of advanced integrated crew station control/display development are:

(1) Layout the display arrangement and necessary controls for a fighter cockpit. Prepare for evaluation of display location, readability, information content, display format acceptability, pilot workload, and mission accomplishment.

(2) Develop display formats (for each mission segment) for all multi-function displays.

(3) Select an existing high performance aircraft to closely approximate the performance required for fighter mission accomplishment in the 1985-1990 time period. Prepare a simulation program that would permit manned, real-time simulations under typical combat conditions.

(4) Generate a simulation plan to evaluate selected display options and compare competing alternatives, in the context of an entire combat mission. Identify evaluation and scoring techniques.

(5) Conduct a Manned Combat Simulation for evaluation of: (a) display arrangement; (b) display formats; (c) display information content; (d) pilot workload; (e) the differences between competing display alternatives; (f) control of computer-generated information; and (g) probability of mission accomplishment and survival.

### 3. DATA BASE

The results of Task 1, Survey and Analysis to Establish Data Base, are presented in the following sections. This task was conducted to provide the data base upon which Tasks 2, 3 and 4 were dependent for direction and scope.

#### 3.1 GROUND RULES

The following ground rules were determined in concert with USAF program goals, as reviewed and approved by the USAF Program Manager 23 September 1977.

(1) Primary emphasis was placed on the Central European Theater (CET). This scenario was used in determining the conditions which impact mission profiles, mission requirements, projected weapons, and subsequently, aircrew functions.

(2) The traditional Tactical Air Command (TAC) missions were used, however, reduced emphasis was placed on the air-to-air missions. Air-to-ground missions received the major emphasis.

(3) Command, control, and communications ( $C^3$ ) systems and the technologies considered for the study, were those available or projected for 1981-1982.

(4) Results from USAF/MCAIR Advanced Tactical Fighter (ATF), Air-to-Surface Technology Study (ATS), and other recent studies are pertinent to this effort and were used wherever applicable.

(5) This study has emphasized the one-man crew station aircraft. A one-man crew station is attractive for several reasons: reduced procurement and operating costs; reduced training cost; and fewer exposed personnel while in combat.

There are, no doubt, missions that can be significantly enhanced by two crew members instead of better systems and a one-man crew station. This is an old and long argument, however, if the one-man crew is never thoroughly explored in a variety of demanding roles, there will never be conclusive evidence for or against it. If, in subsequent work, analysis identifies areas that can be better performed by a two-man crew, they will be reported. In the meantime, the merits of one-man crew station demand a thorough study in order to best manage the complicated requirements of the tactical air environment.

(6) Predicted vehicle characteristics typical of the high performance fighters anticipated for future systems (including direct force control) were utilized.

(7) Primary ordnances are stand-off type weapons.

(8)  $C^3$  as currently projected will include as a minimum:

(a) Airborne Warning and Control System (AWACS)

- (b) Global Positioning Satellite (GPS)
- (c) Joint Tactical Information Distribution System (JTIDS)

(9) Aircraft systems considered in the course of this study are compatible with advanced technology (ECM, navigation, radar, etc.)

(10) Primary emphasis throughout the study is the man/machine interface.

(11) Two engine aircraft.

(12) High Acceleration Cockpit (HAC) configurations.

(13) Definitions are those officially accepted by NATO, USAF, or DOD.

(14) Configuration utilizes:

- (a) HUD as primary attitude reference
- (b) Multifunction displays
- (c) Multifunction control unit
- (d) Fly-by-wire stick and throttle control
- (e) Mass storage device (Disc, bubble memory, etc.)

(15) Documents considered basic to this study are:

- (a) Tactical Air Command Manual 3-1 (TACM 3-1)
- (b) Air-to-Surface Technology Reports, Reference (1)
- (c) Joint Chiefs of Staff Publication 1
- (d) NATO Glossary, AAP-6(N)

### 3.2 MISSION PROFILES

Tactical Air Power (TACAIR), as it exists today, defines three primary missions to accomplish the more general USAF objectives of being able to wage and win wars. The primary TACAIR missions are Close Air Support, Air Interdiction, and Counter Air. Although there are other TACAIR missions, such as Reconnaissance and Electronic Warfare, they are considerably more specialized and, in general, are designed primarily to support TACAIR's offensive air-to-air and air-to-ground missions.

The official definitions of each mission follow as taken from Joint Chiefs of Staff PUB 1, the NATO Glossary, AAP-6(N), and NATO ATP-27(A).

Close Air Support - Air action against hostile targets which are in close proximity to friendly forces and which require detailed integration of each air mission with the fire and movement of those forces.

Air Interdiction - Air operations conducted to destroy, neutralize, or delay the enemy's military potential before it can be brought to bear effectively against friendly forces, at such distance from friendly forces that detailed integration of each air mission with the fire and movement of friendly forces is not required.

Counter Air - Air operations conducted to attain and maintain a desired degree of air superiority by the destruction or neutralization of enemy forces. Both air offensive and air defensive actions are involved. The offensive actions range throughout enemy territory and are generally conducted at the initiative of the friendly forces. The defensive actions are conducted near to or over friendly territory and are generally reactive to the initiative of the enemy air forces.

Two other definitions are required to complete a basic knowledge of TACAIR mission related terminology. These are:

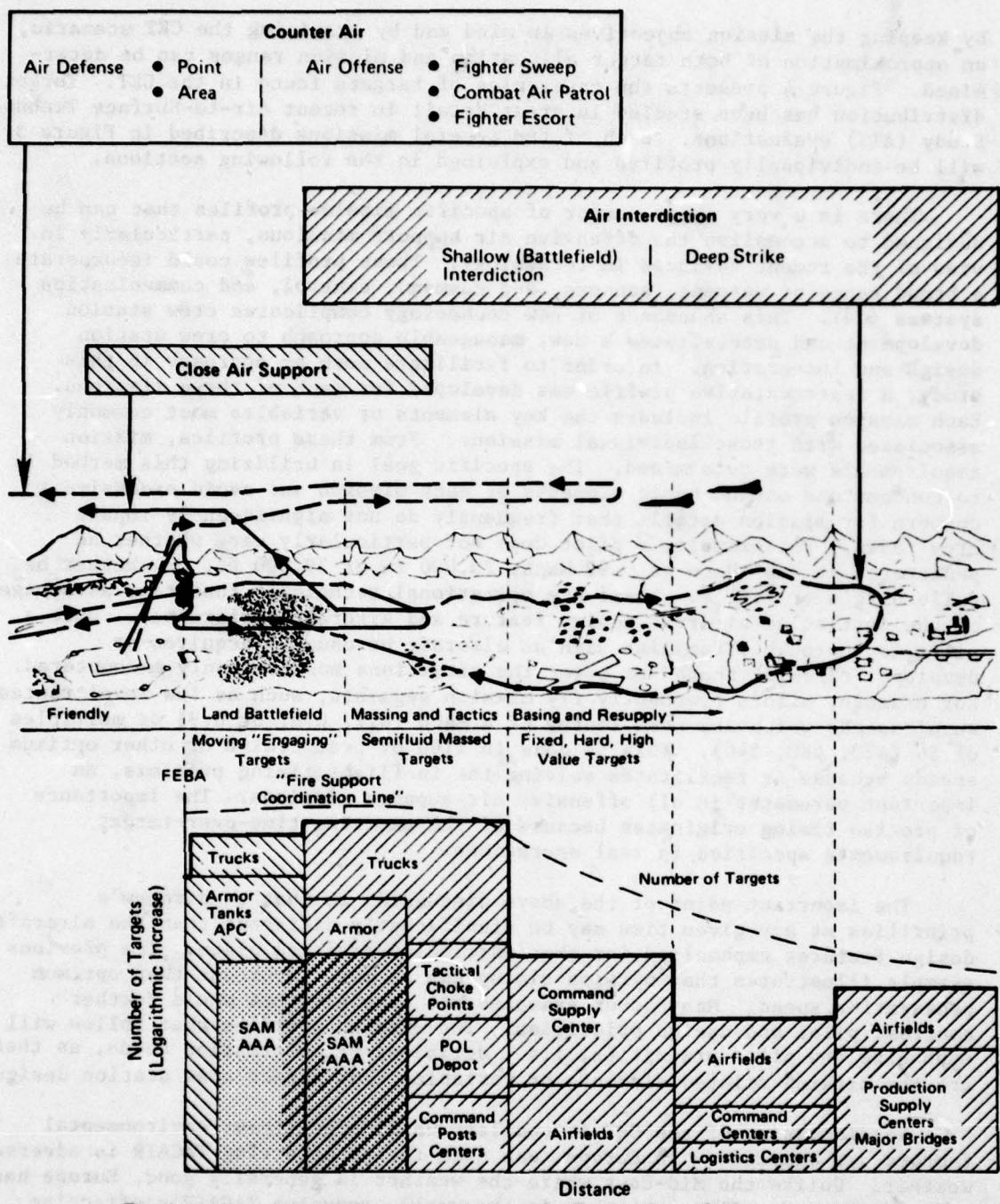
Air Superiority - That degree of dominance in the air battle of one force over another which permits the conduct of operations by the former and its related land, sea, and air forces at a given time and place without prohibitive interference by the opposing force.

Air Strike - An attack on specific objectives by fighter, bomber, or attack aircraft on an offensive mission. May consist of several air organizations under a single command in the air. (JCS PUBL and NATO Glossary, AAP-6(N))

The primary emphasis of this study was on the requirements identified from the two air-to-ground missions, which are Air Interdiction and Close Air Support. Consideration was also given to the air-to-air role, Counter Air, but primarily in relation to defensive actions. This allocation of study time and resources allowed for a better coverage of those elements most likely to affect the development of the next advanced fighter and are in keeping with a general overview of our current and planned force structure. For example, a brief look at current tactical fighters and those planned in the next 5 years illustrate that the heavy dollar emphasis has been placed on air-to-air weapons, such as the F-14, F-15, and F-16. In view of a constantly increasing WARSAW PACT threat to NATO, which emphasizes armor, artillery and fast moving ground attacks, it is logical to anticipate the next USAF fighter aircraft will emphasize weapons delivery against the types of targets and under the environmental conditions that would be encountered in the CET. This logic suggests that new aircraft programs will emphasize an air-to-ground weapons system.<sup>1</sup> In addition, a credible defensive air capability is always a desirable feature on fighter aircraft, since this ability retains a multirole aircraft classification. The defensive air feature also reduces the requirement for fighter escort, which if not done, would cause a further reduction in the resources available to maintain Air Superiority.

Figure 3 summarizes, in general, the scope of TACAIR's offensive air support missions. The mission definitions previously listed specify neither target types nor the range at which the missions will be conducted. However,

1. NOTE: This analysis does not presume that the Counter Air role is well in hand. High altitude, high speed enemy aircraft, such as FOXBAT, and a significant advantage in total enemy aircraft, are always cause for concern when planning future force levels.



The above drawing represents the scenario in use for Tactical Air-to-Surface studies being conducted by a joint laboratory team.

Targets suitable to other missions.

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**Figure 3**  
**TACAIR Missions**

by keeping the mission objectives in mind and by examining the CET scenario, an approximation of both target allocation and mission ranges can be determined. Figure 4 presents the categories of targets found in the CET. Target distribution has been studied in great detail in recent Air-to-Surface Technology Study (ATS) evaluations. Each of the general missions described in Figure 3 will be individually profiled and explained in the following sections.

There is a very large number of specific mission profiles that can be designed to accomplish the offensive air support missions, particularly in view of the recent advances in technology. These profiles could incorporate a broad range of weapons, sensors, and command, control, and communication systems (C<sup>3</sup>). This abundance of new technology complicates crew station development and necessitates a new, manageable approach to crew station design and integration. In order to facilitate such an approach in this study, a representative profile was developed for each of three missions. Each mission profile includes the key elements or variables most commonly associated with those individual missions. From these profiles, mission requirements were determined. The specific goal in utilizing this method is to concentrate on the basic elements of each mission and avoid excessive concern for mission details that frequently do not significantly impact crew tasks. For example, a pilot does not particularly care whether he penetrates at 0.85 Mach or 0.92 Mach, 25,000 ft or 29,000 ft, or whether he pulls 6.2g's or 7.1g's. These are operational techniques that take advantage of the particular aircraft design feature and aircraft performance. Once a pilot is thoroughly familiar with an aircraft he usually acquires or develops "rules of thumb" to cover the situations most commonly encountered. For example, pilots frequently fly mission segments, such as low level routes, at airspeeds which are even tenths of a Mach (0.7, 0.8, or 0.9) or multiples of 60 (420, 480, 540). This is done in lieu of best cruise or other optimum speeds because it facilitates solving the in-flight timing problems, an important parameter in all offensive air support missions. The importance of precise timing originates because of the exacting time-over-target requirements specified in real operations.

The important point of the above discussion is that an aircrew's priorities at any given time may be significantly different than the aircraft design features emphasized for that particular time and place. The previous example illustrates that mission timing can be more important than optimum penetration speed. Many other examples are possible that would further contrast pilot and design priorities. The mission profiles that follow will emphasize the pilot priorities, i.e., decisions or information needs, as these are the mission related elements or variables that affect crew station design.

No discussion of the CET is complete until significant environmental factors are examined. In Europe, one such factor affecting TACAIR is adverse weather. Unlike the Mid-East where the weather is generally good, Europe has some of the worst flying weather in the world, reducing TACAIR's effectiveness. For example, optical or visible spectrum limited weapons are very good in clear skies (Mid-East), but are reduced in effectiveness or altogether negated in the CET environment. This very serious handicap greatly complicates TACAIR's CET mission.

**Short Range Mission**

Target	Number of Targets in NM Increments								Total
	0-15	15-30	30-45	45-60	60-75	75-90	90-105	105-120	
Mobile SAMs									
Armored Column									
Armor March Formation									
EW/GCI Radar Sites									
Bridge-Highway									
Mobile SAMs									
Armored Column									
Armor March Formation									
EW/GCI Radar Sites									
Bridge-Highway									

**Long Range Mission**

Target	Number of Targets in NM Increments										Total
	0-25	25-50	50-75	75-100	100-125	125-150	150-175	175-200	200-225	225-250	
Air Defense Control Center											
Hardened Command Control Center											
Airfields											
Aircraft Shelters											
POL Storage Site											
EW/GCI Radar Sites											
Fixed SAM Site											
Bridges-Railway											
Resupply Column											

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**Figure 4**  
**Central Europe Target Distribution**

Figures 5 and 6 summarize the weather and the day/night conditions found annually in Europe. They clearly show that the flying weather in the winter months is the most severe. Overall, if day or clear skies are required for effective systems operation, then TACAIR, as currently structured, is tremendously handicapped!

Figure 7 illustrates an attack of a hypothetical Soviet tank division in breakthrough formation. Therein lies several key elements which must be evaluated in a CET scenario and subsequent mission profiles. They are:

- (1) Enemy tanks are concentrated at the battle front and are in close proximity to friendly forces.
- (2) The battlefield terrain can vary considerably.
- (3) Surface-to-Air Missiles (SAM's) are distributed throughout the WARSAW PACT division and provide overlapping hemispheres of protective coverage for the ground forces (See Figure 8).

These elements further complicate an aircrew's ability to find and attack the right target and still survive.

The CET, in the final analysis, is a hostile battle environment. The weather, enemy offensive and defensive forces, terrain, and tactics make the CET the most complex battlefield ever encountered. Therefore, the mission profiles that follow (Figures 9 through 11) emphasize the pilot priorities, i.e., decisions or information needs, as these are the mission related elements or variables that affect crew station design.

### 3.3 MISSION REQUIREMENTS

The mission phases are summarized in Figure 12. This figure lists the phases of the three primary missions for which the mission requirements (Appendix B) were generated. The mission phases were derived directly from the mission profiles presented in Figures 9 through 11. Each mission requirement was examined for the key elements and differences between the three TACAIR missions. A tabulation of mission requirements is found in Appendix B. The format used allows the easy comparison of the three general missions and, in Task 2, aided in the determination of the individual crew information requirements. Notes are included where further clarification or differentiation of a particular mission phase is needed.

These requirements were constructed from a combat pilot's viewpoint and stress those items with which he is primarily concerned during a particular mission phase. Although they are, in this study, considered individually by phase and task, in real life they would always overlap. The aircrew would constantly evaluate several of the tasks in a mental "time sharing" process.

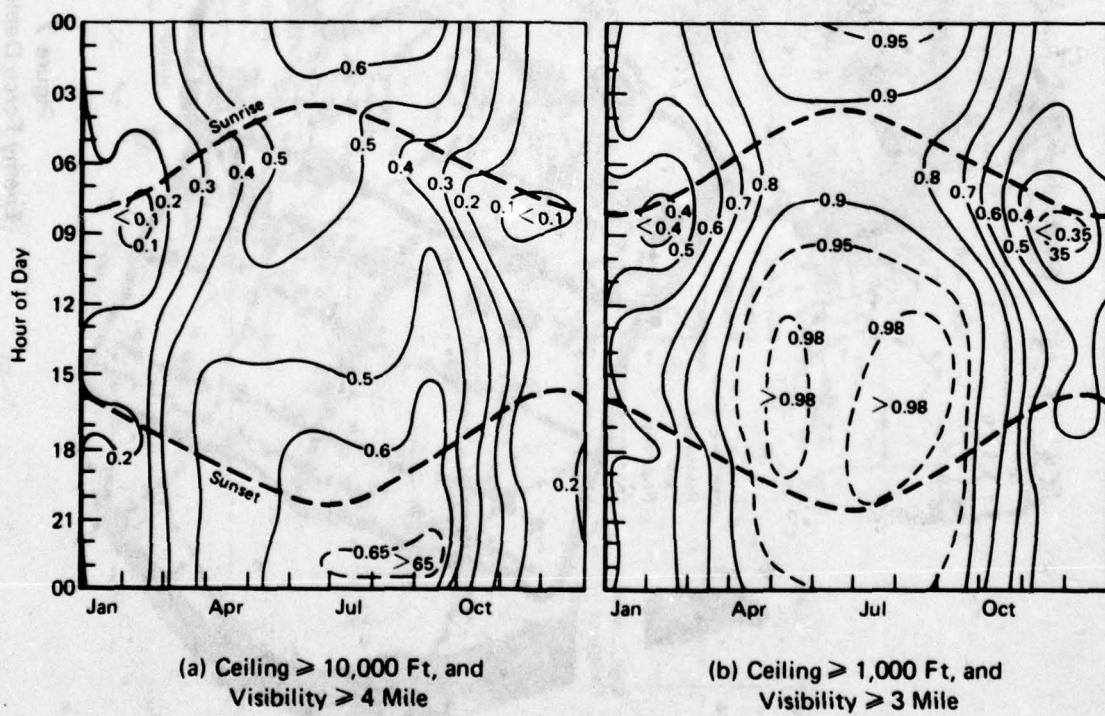
The cloud layer over Western Europe is typically low and scudding on westerly winds. The average ceilings (more than 50% cloud cover) expressed as a percentage for three month periods in West Germany are:

	Mar-May	Jun-Aug	Sep-Nov	Dec-Feb
No Ceiling	29.7%	33.9%	25.1%	15.7%
2000 Plus	49.2	50.2	42.3	41.2
1500-2000	3.9	2.4	4.0	5.6
1000-1500	5.4	3.9	6.2	9.8
500-1000	6.5	5.0	8.0	14.1
Under 500	5.3	4.6	14.4	13.6
Average	6.2	6.7	18.5	17.1

Source: U.S. Army FM 100-5

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**Figure 5**  
Typical West German Ceiling Levels



Source: USAF Project Rand R-1195-1-PR Jan 1974

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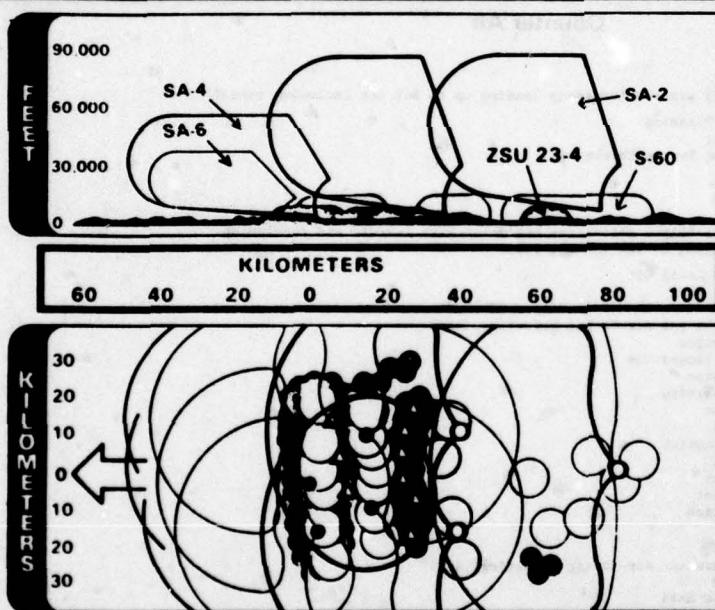
**Figure 6**  
Probability that Ceiling and Visibility Values Equal  
or Exceed the Given Limits



**Figure 7**  
**Enemy Force Deployment**  
**Close Air Support Target Array**

**FM 100-5**  
**HEADQUARTERS**  
**DEPARTMENT OF THE ARMY**  
**Washington, D.C. 1 July 1976**

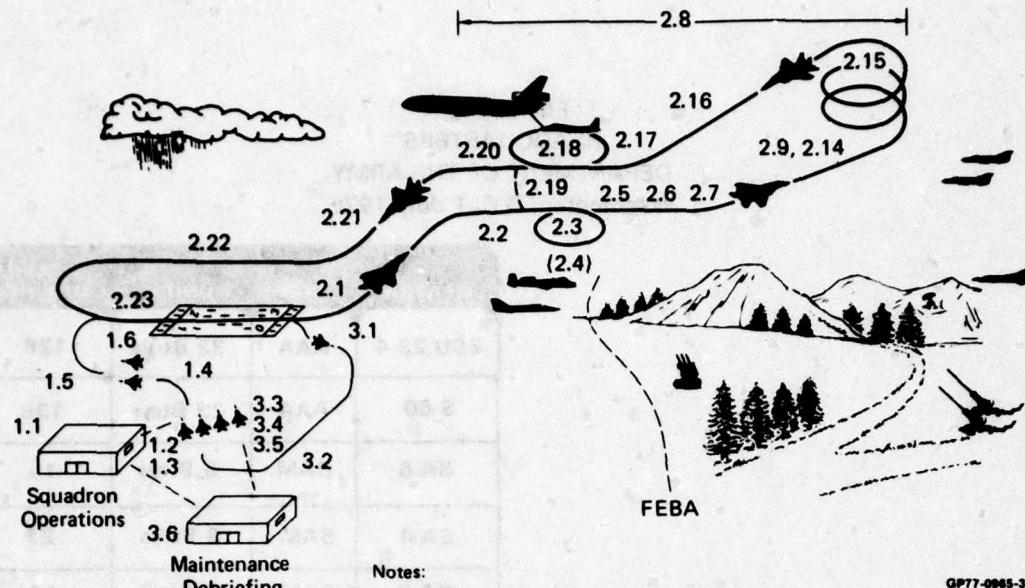
WEAPON	TYPE	UNITS	WEAPONS LAUNCHERS
ZSU 23-4	AAA	32 Btrys	128
S-60	AAA	23 Btrys	138
SA-6	SAM	5 Btrys	15
SA-4	SAM	9 Btrys	27
SA-2	SAM	3 Btrys	18



This figure portrays a typical Soviet Combined Arms Army air defense system 50 kilometers wide and 100 kilometers deep. Shoulder-fired SA-7 and vehicle-mounted SA-9 launchers common to all units are not shown, but provide a dense blanket of low altitude air defense which complements the other systems.

LEGEND	
○	SA-2 3 Batteries
○	SA-4 9 Batteries
○	SA-6 5 Batteries
○	S-60 23 Batteries
●	ZSU 23-4 - 32 Batteries ZSU 23-2 - 19 Batteries ZSU 57-2 - 6 Batteries

**Figure 8**  
**Enemy Air Defenses**



Notes:

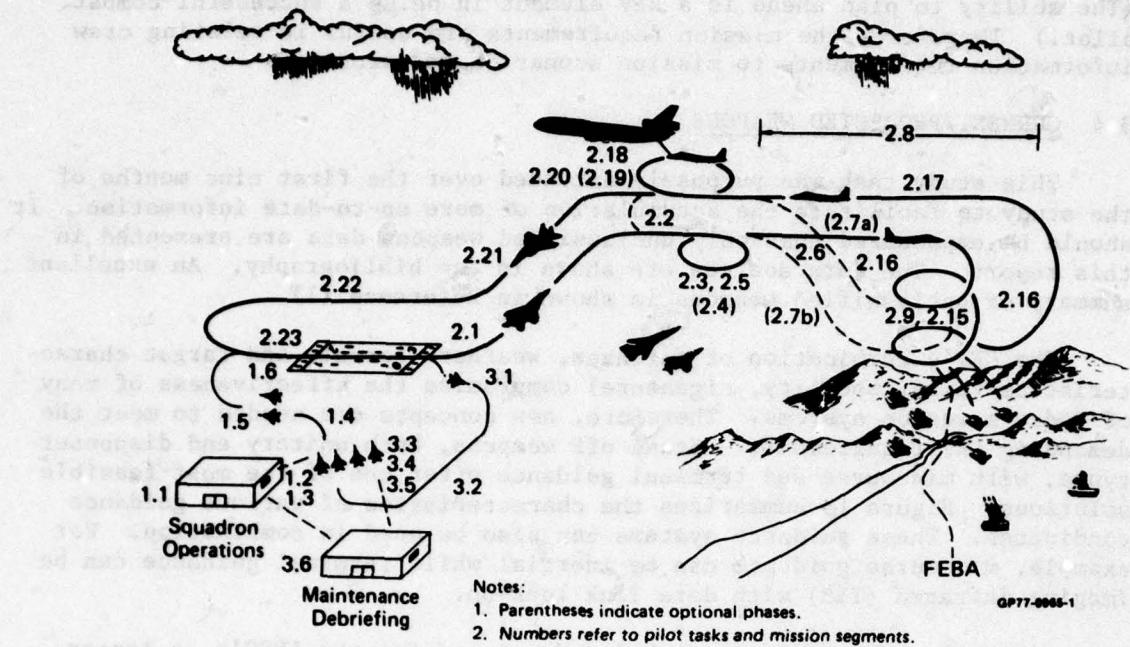
1. Parentheses indicate optional phases.
2. Numbers refer to pilot tasks and mission segments.

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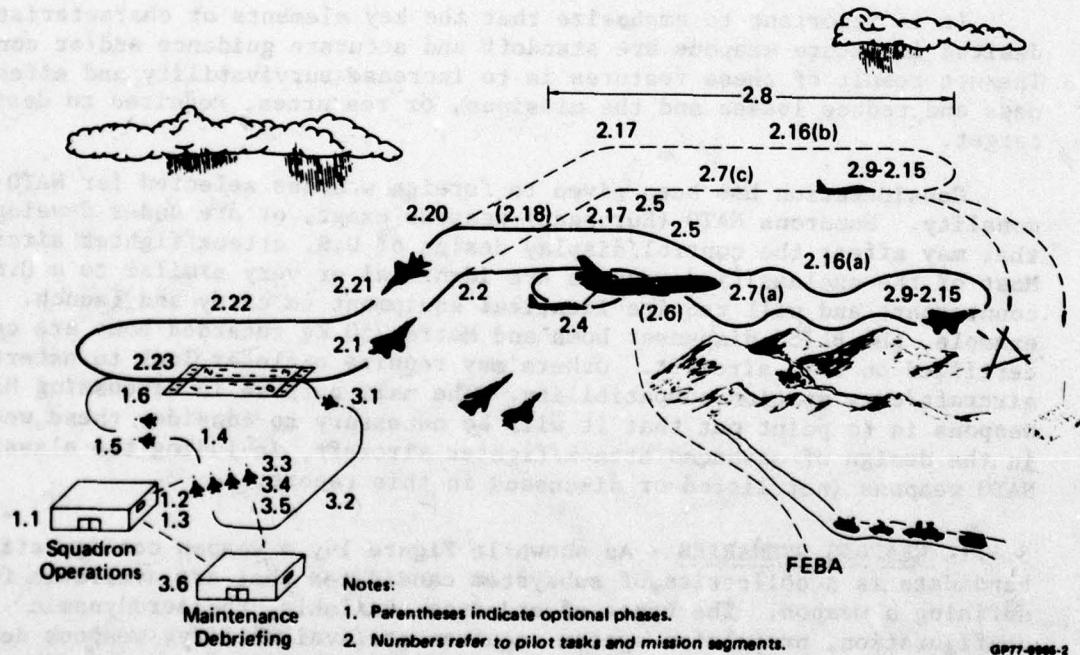
**Figure 11**  
**Counter Air**

1. Preflight - All aircrew functions leading up to but not including takeoff.
  - 1.1 Mission Planning
  - 1.2 Preflight
  - 1.3 Start and System Checks
  - 1.4 Taxi
  - 1.5 Arming
  - 1.6 Takeoff
2. In-Flight - All flight activities beginning with takeoff and concluding at the termination of the landing roll.
  - 2.1 Climb to Level Off
  - 2.2 Cruise
  - 2.3 Loiter
  - 2.4 Rendezvous and Air-to-Air Refueling (AAR)
  - 2.5 Coordination
  - 2.6 Mission Rendezvous
  - 2.7 Penetration
  - 2.8 Threat Warning
  - 2.9 Detection
  - 2.10 Location
  - 2.11 Identification
  - 2.12 Decision
  - 2.13 Execution
  - 2.14 Assessment
  - 2.15 Termination
  - 2.16 Egress
  - 2.17 Cruise
  - 2.18 Rendezvous and Air-to-Air Refueling (AAR)
  - 2.19 Reengage
  - 2.20 Return to Base
  - 2.21 Descent
  - 2.22 Approach
  - 2.23 Landing
3. Post-Flight - All mission related activities beginning after the completion of the landing roll and ending when the aircrew is free to perform other duties or pursue personal interests.
  - 3.1 De-arm
  - 3.2 Taxi
  - 3.3 System Checks
  - 3.4 Shutdown
  - 3.5 Post-Flight
  - 3.6 Debrief

**Figure 12**  
**Mission Requirements: Phases of Flight**



**Figure 9**  
**Close Air Support**



**Figure 10**  
**Air Interdiction**

(The ability to plan ahead is a key element in being a successful combat pilot.) Therefore, the mission requirements are useful in relating crew information requirements to mission scenarios and profiles.

### 3.4 CURRENT/PROJECTED WEAPONS

This study task was purposely extended over the first nine months of the study to facilitate the accumulation of more up-to-date information. It should be emphasized that only unclassified weapons data are presented in this report. The data sources are shown in the bibliography. An excellent summary of unclassified weapons is shown in Reference (1).

The CET's combination of defenses, weather, terrain and target characteristics (size, mobility, signature) compromise the effectiveness of many of today's weapon systems. Therefore, new concepts are needed to meet the demanding CET requirements. Stand off weapons, both unitary and dispenser types, with midcourse and terminal guidance offer one of the most feasible solutions. Figure 13 summarizes the characteristics of various guidance candidates. These guidance systems can also be used in combination. For example, midcourse guidance can be inertial while terminal guidance can be imaging infrared (IIR) with data link lock-on.

Although these weapons are being developed for the 1980's, a larger number of today's weapons (Maverick, Rockeye, MK84) will still be in the inventory and could still receive a great deal of use, depending on the time and duration of a future conflict.

It is important to emphasize that the key elements or characteristics desired in future weapons are standoff and accurate guidance and/or control. The net result of these features is to increase survivability and effectiveness and reduce losses and the missions, or resources, required to destroy a target.

Consideration has been given to foreign weapons selected for NATO commonality. Numerous NATO (European) weapons exist, or are under development, that may affect the control/display design of U.S. attack/fighter aircraft. Most of the unclassified weapons are identical or very similar to a U.S. counterpart and will require identical equipment to carry and launch. For example, the BL755 dispenser bomb and Matra 250 Kg retarded bomb are currently certified on U.S. aircraft. Others may require a closer look to ascertain aircraft/crew station compatibility. The main purpose in discussing NATO weapons is to point out that it will be necessary to consider these weapons in the design of advanced attack/fighter aircraft, including the classified NATO weapons (not listed or discussed in this report).

**3.4.1 WEAPONS SUMMARIES** - As shown in Figure 14, a weapon configuration candidate is a collection of subsystem candidates that are available for defining a weapon. The types of ordnance available, the aerodynamic configuration, propulsion system requirements/availability, weapons delivery guidance systems and support systems are typical of those weapon subsystems necessary to define a successful weapon. Certainly midcourse and terminal

guidance are two of the most important subsystems in weapons design without which the weapon could not reach the selected target. Figures 15 and 16 list midcourse and terminal guidance concepts, respectively, with assigned priorities for continued development based on anticipated capabilities.

Generic Guidance Type	Candidate Characteristics					
	Adverse Weather	Fixed Targets	Moving Targets	* LOBL	** LOAL	Launch and Leave
Laser Seeker	-	✓	✓	✓	✓	-
EO Tracker (Edge, Centroid, Correlation) Lock On Before Launch Data Link Lock On	-	✓	✓	✓	-	✓
IIR Tracker (Edge, Centroid, Correlation) Lock On Before Launch Data Link Lock On	-	✓	✓	✓	-	✓
IR/Radiometric Seekers (Passive)	✓	✓	✓		✓	✓
Radar Contrast Trackers SAR Line of Sight SAR Azimuth/Range Coincidence Radar Correlation	✓ ✓ ✓ ✓	✓ ✓ ✓ ✓	✓ ✓ ✓ -	✓ - - ✓	✓ ✓ ✓ ✓	✓ - - ✓
IR/Radiometric Correlators	✓	✓		✓	✓	✓
Terrain Correlators (TERCOM)	✓	✓		✓	✓	✓
Antiradiation	✓	✓		✓		✓
Inertial	✓	✓		✓	✓	✓

\*Lock-on before launch

\*\*Lock-on after launch

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**Figure 13**  
**Guidance Candidates and Characteristics**

- **Ordnance**
  - Warhead
  - Fuze
- **Aero Configuration**
  - Nose
  - Body
  - Lifting Surfaces
  - Control Surfaces
- **Propulsion**
- **Weapon Delivery**
  - Midcourse Guidance
  - Terminal Guidance
- **Support**
  - Autopilot
  - Control System
  - Prime Power

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**Figure 14**  
**Weapon Subsystem Candidates**

Description	Priority	Comment
Unaided Inertial	High	
TERCOM	High	
Radar Image Corr	High	
EO Image Corr	Low	Not Adverse Weather
RAC	High	
Command (SAR)	High	
Antiradiation Homing	Low	Special Purpose
DME	Low	Not Autonomous
GPS	Low	Not Autonomous
LORAN	Low	Not Autonomous

**Figure 15**  
**Screening of Midcourse Guidance Concepts**

Description	Priority	Comment
Active/Passive MCG	High	
Radar Seeker	High	Covered Above
Antiradiation Homing	Low	Special Purpose
SAR-Aided	High	
EO/IR Imaging	Low*	Not Adverse Weather
Laser Tracker	Low	Not Adverse Weather

\*Imaging IR is considered necessary for bridge target for aimpoint control

**Figure 16**  
**Screening of Terminal Guidance Concepts**

Figure 17 summarizes the types of air-to-air missiles that must be considered in designing the controls/displays of an advanced attack/fighter crew station. The physical characteristics are listed as well as the aircraft system components required to permit a successful missile deployment. Important to the crew station designer are the "cockpit components required" to launch each type of missile. The basic purpose of each missile has been provided in the "Remarks" column.

Designation	Characteristics	Aircraft System Components Required	Cockpit Components Required	Remarks
1. BDM	Interellar rocket/ramjet; homing	Unknown	MMI, SMS, CNTRLS, release switch	Bomber defense missile for B-1
2. BRAZO	Radar homing	RHAWIS; Stores release system	SMS; release switch; slew control	Antiradiation missile
3. FALCON (AIM-4F)	7.1' length; 140 lb; semi-active pulse radar homing; Mach 3; 5 nm range	None; Stores release system	SMS; release switch; IR guidance	Used on F-106; AIM-4C has IR guidance
4. PHOENIX (AIM-54A)	13.0' length; 1000 lb; semi-active radar homing	Radar; Stores release system	MMI, SMS; release switch	For use on F-14A
5. Genie	9.6' length; 800 lb; unguided; nuclear warhead	Stores release system	Multimode display; PAL nuclear armament panel; release switch; radar hand controller	Used on F-106
6. Sidewinder (AIM-9E-L)	Approximately 10' length; 180 lb; infrared homing	Stores release system	Aural tone, HUD, SMS, slew control; release switch	Various capabilities up to all aspect capability
7. Sparrow (AIM-7E, F)	12.0' length; 450-500 lb; semi-active (cw) radar homing; 12-24 nm range	Radar, mission computer, Stores release system	MMI, SMS, release switch	Used on F-4, F-14, F-15 and F-18
8. Guns: 20MM	High velocity projectiles	Radar, mission computer, Stores release system	HUD; release switch	
9. AMRAAM	Command inertial mid-course active radar terminal. Physical characteristics undefined.	Undefined	Goal: Compatible with existing Sparrow/side-winder switchology	Goal: Compatible with F-14, F-15, F-16 & F-18 aircraft. (In competition stage)

Figure 17  
Air-to-Air Missiles

Figures 18 and 19 list similar information for air-to-surface ballistic weapons and air-to-surface missiles, respectively.

### 3.5 AVIONIC FUNCTIONS

To insure compatibility with contemporary as well as advanced avionic concepts and equipment, avionic data (including controls and display information) was assessed from advanced programs such as ATF (Advanced Tactical Fighter), ATS (Air to Surface Technology Study), AFTI-15 (Advanced Fighter Technology Integration with the F-15 baseline aircraft), F-18, DAIS (Digital Avionics Information System) and AIDS (Advanced Integrated Display System), References (2) and (3). The general result of the assessment is that large scale integration (LSI) technology and microprocessors will improve performance and reliability while modularity will reduce costs. Controls and displays will be closely tied to the computer systems and will be multifunction rather than dedicated.

The reduction in the cost of integrated circuitry per unit of function, the advantages of the memory, and accuracy of digital circuitry are resulting in an increase in the use of digital computers in military aircraft. Most importantly, the avionics are becoming more integrated, with the various subsystems under the control of higher level systems, themselves under the control of the pilot. By effective interconnection and integration of subsystems the crew task-load can be reduced, with the pilot concentrating on tasks which a computer cannot handle effectively.

The advances in electronics are leading to improvements in sensors and data processing capabilities. This will result in more accurate navigation, improved night and adverse weather target detection, jam resistant communications and more effective electronic countermeasures. The largest payoff in terms of military effectiveness may be achieved with better command, control and communications. The programs most likely to directly affect aircraft systems and crew information requirements are the Joint Tactical Information Distribution System (JTIDS) and the Airborne Warning and Control System (AWACS). Although not directly a C<sup>3</sup> program, the Global Positioning System (GPS) may directly interface with JTIDS for navigation and blind navigation bombing capabilities. A summary of avionics in DAIS is presented in Figure 20 and of the Multifunction Control, Voice Actuated Systems, JTIDS, AWACS, and GPS in the succeeding paragraphs.

**3.5.1 MULTIFUNCTION CONTROL UNIT** - The key technology in the development of a Multifunction Control Unit involves multilegend switches. There are several ways in which the multilegend switching capability can be implemented. These include:

- (a) Rear projected legends onto a pushbutton switch.
- (b) Generating legends remotely and transmitting to switch face with fiber optics.

Designation	Characteristics	Aircraft System Components Required	Cockpit Components Required	Remarks
1. Modular Glide Bomb (GBU-15)	Winged 2000 lb bomb; modules	Stores release system	Slew control, HUD or sight; release switch	Could also use DME or laser guidance
2. MK-82	500 lb; 86 in.	Stores release system	Aiming sight or HUD; release switch	General purpose munition
3. MK-84	2000 lb; 12' 8" length	Stores release system	Aiming sight or HUD; release switch	General purpose munition
4. Guns: 20MM 30MM	High explosive incendiary Gun system			
5. MK-117	750 lb; 90 in.	Stores release system	HUD or sight; release switch	General purpose munition
6. RDU-351 (MK-84 laser guided)	2052 lb; 14' length	Stores release system	Laser detector; HUD or sight; release switch	
7. MK-82 Snakeye	560 lb; 84 in.	Stores release system	HUD or sight; release switch	High drag version of MK-82
8. CBU-30/A; 90.4 in.	385 lb	Stores release system	HUD or sight; release switch	Cluster munition loaded with 1280 BLU-39/B23 bomblets
9. CBU-24, 49, 52, 58, and 71	820 lb; clam shell; 88 in.	Stores release system	HUD or sight; release switch	Loaded with 670 bomblets, except CBU-52, which has 217 bomblets
10. Rockeye II	485 lb; 93 in.	Stores release system	HUD or sight; release switch	Dispenser weapon loaded with 247 MK-118 M0D0 bomblets
11. BLU-1C/B, 27/B Fire Bomb	100 gals; 143 in.	Stores release system	HUD or sight; release switch	Filled with incendi gel

Figure 18  
Air-to-Surface Ballistic Weapons

<b>Designation</b>	<b>Characteristics</b>	<b>Aircraft System Components Required</b>	<b>Cockpit Components Required</b>	<b>Remarks</b>
1. ALCM (AGM-86)	19' length; 2800 lb; inertial/tercom	Inertial navigation system; Stores release system Unknown	Control head, SMS; release switch Slew control; release switch	Strategic nuclear role with B-1 and B-52 Being phased out of inventory
2. Bullpup A (AGM-12B)	11.0' length; 571 lb; command guidance; 250 lb warhead; 6 nm range	RHAWs; Stores release system	MND; SMS; release switch	High velocity anti-radiation
3. HARM (AGM-88A)	13.7' length; 770 lb; radar homing	Stores release system	MND; release switch	Anti-ship missile
4. Harpoon (AGM-84A)	12.5' length; 1170 lb; active radar; 50+ NM range	Stores release system	MND; controls, slew control; release switch	Laser and imaging infrared Maverick under development. Useful against tanks
5. Maverick (AGM-65A/B)	8.2' length; 475 lb; television guided	Stores release system	MND; controls, slew control; release switch	Used on Wild Weasel aircraft (F-105G and F-4G)
6. Shrike (AGM-45B)	10.0' length; 400 lb; passive radar homing	RHAWs; Stores release system Unknown	Aural tone; release switch Release switch	Short range attack missile for B-1, FB-111, and late Model B-52's
7. SRAM (AGM-69A)	14.0' length; 2230 lb; inertial guidance; 120 nm range	RHAWs; Stores release system	MND; lock on indication; release switch	Anti-radiation missile
8. Standard ARM (AGM-78C/D)	14.9' length; 1355 lb; radar homing	Data link; Stores release system	MND; slew control; communication CNTRL head; release switch	Unpowered TV guided glide weapon
9. Walleye 1, 2	11.3-13.25' length; 2400 lb; television data link			

**Figure 19**  
**Air-to-Surface Missiles**

Function	Equipment Type	Anticipated Advances
NAV	Inertial	Strapdown; improved gimballed systems
	ADC	Computations performed in processor
	TACAN, ILS, ADF	Weight, size, power consumption
	GPS, OMEGA	Will become operational
	Hybrids	GPS/inertial available
COM		MSI, LSI; Shared Antennas; Modulation techniques
	JTIDS	Will become operational
IFF		Improved performance, cost reductions
ECM		Power management
Air/Ground Attack	Lasers	Laser target seekers will become operational
	FLIR	Reduced costs, weight, size; improved display
	FLR	Improved performance, reliability
C/D	Controls & Displays	Current displays and controls will be replaced by computer-driven MPD's plus IMFK's
Processing		LSI technology and microprocessors with large central processing capability
		BITE contained within microprocessors
		MOS (metal oxide semiconductors) Bipolar Schottky transistor-transistor logic
Power Supply		Central power supply core element
Interface Equipment	BCIU, RTU	Integrated within sensor or processor

**Figure 20**  
**Technology Advances Available for Mid-1980s DAIS**

- (c) Generating legends on an electronic display with switches around periphery.
- (d) Generate legends on an electronic display and sense area which has been designated (touch, light pen, photo-sensitive detectors, etc.)
- (e) Generate legends on the switch face.

The technology exists for methods (a) through (d), but not all these devices are suitable for flight operations. Method (e) is potentially the most promising, but implies the need for flat-panel display capability. Currently the most promising for alphanumerics are LED and LCD (see Section 5.3, Display Technology Evaluation). The problem with virtually all flat panel display media is the large number of leads necessary for the X-Y addressing schemes.

Rear projected legend switches are typically large when several legends are required for each switch, and are inadequate in brightness requirements.

A fiber-optic read-out switch, method (b), appears technically feasible as many fiber-optic display presentations are currently being used in proposed flight hardware. The legends can be generated from CRT, film, etc. and the light transmitted to the switch through fiber optics.

Method (c) is technically acceptable and is to be used in the F-18. This is a useful concept when the display is to be used for additional purposes besides a control function but is not space efficient for a "dedicated" control unit.

Method (d) can simplify the addressing logic through use of a CRT raster for the electronic display. Transparent, touch-sensitive switches are commercially available for overlaying the CRT face. When one touches (< 1 lb pressure) a spot on the overlay a binary code is generated in relation to the area designated. The major disadvantage of this approach is the potential adverse characteristics under vibration.

**3.5.2 VOICE ACTUATED CONTROLS** - As modern aircraft become increasingly more sophisticated, additional pilot responsibilities are created imposing new tasks on an already burdensome pilot workload. The concept of voice actuated systems (VAS) as one potential solution to this problem is becoming an area of mounting interest. An indication of this current interest may be noted in the proceedings of a conference on voice technology for interactive, real-time command/control systems application, from which a large portion of this information is drawn. The conference held in December 1977 was jointly sponsored by the Naval Training Equipment Center, Naval Air Development Center and the National Aeronautics and Space Administration. In addition, there are more than a dozen government agencies currently engaged in supporting voice development efforts.

The purpose of VAS is to permit direct communication with a computer, thereby reducing workload and providing additional time to perform higher skill level tasks.

The particularly desirable applications of VAS are: reduce manual control procedures (especially during critical flight phases); minimize eye-hand coor-

dination problems; and reduce visual demands inside the cockpit, all of which allow more time to focus outside the cockpit or on more prominent tasks. A representative example may be found in the weapons delivery mission phase for a single-seat fighter aircraft. During this mission segment, the pilot is concerned with the sequence of events necessary to properly arm and deliver weapons on a target, maintain altitude and airspeed within acceptable limits, perform required communications, and remain alert for enemy threats. With a VAS, it may be possible for the pilot to merely voice the changing of radio channels as well as the sequence of events necessary to arm and deliver weapons. Hence, the alleviation of these two tasks allows more time and attention to be given to target acquisition, lock-on, flight control and threat avoidance.

Research efforts in the area of voice control may be found as early as 1955. Very generally, it is reasonable to say that the state of the art in VAS has passed from infancy to adolescence. Ongoing research efforts are numerous in both industrial and government settings. Voice actuated systems are being tested and evaluated under simulated cockpit environments. These systems are in various stages of design and implementation and represent a practical utilization of voice recognition technology.

Voice data entry systems for a number of interactive command and control functions are already in use. Although, these applications are limited to a small vocabulary, speaker dependent, isolated word recognition systems that are highly reliable. Vocabularies typically consist of digits and a limited set of control words and phrases. For all practical purposes, speaker dependent isolated word recognition has been solved under laboratory conditions. Voice data entry system applications include automatic sorting systems for the distribution of parcels, containers and baggage, voice programming for machine tools, inspection systems, and automobile quality control. Despite these applications, two general problem areas still exist. The first deals with problems in the speech processing/recognition process. These include the training of the speakers in the use of the word recognizer, development of adaptive techniques to upgrade word patterns as a function of time, and decreasing the error rate. The second area deals with problems of incorporating the word recognition device into an operational system. This includes teaching the speaker to use the system in the same manner as it would be used in an operational environment, developing corrective procedures to reduce the amount of time taken to correct a mistake, and developing an efficient feedback system. Although it is true that more research is needed in the area of VAS, isolated systems are currently capable of solving a wide range of present day problems.

Relevant VAS programs at McDonnell Douglas include improving the quality of synthesized speech as well as devising improved methods for analysis and definition of articulatory speech for use in generating message system vocabularies for airborne warning systems. Work has also been conducted on extending the capabilities of automatic word recognition for direct man/computer communication, improving automatic speaker verification and improving the capabilities for continuous speech recognition. A joint venture by MDC Electronics Co. and MDC Astronautics, directed toward airborne applications of VAS, is currently under active consideration. A rudimentary voice system has also been constructed at MDAC-St. Louis for laboratory evaluations and VAS-related research is currently being planned.

**3.5.3 JTIDS** - The Joint Tactical Information Distribution System (JTIDS) is a digital, secure, jam-resistant, communication system for real-time command and control of combat operations. JTIDS is planned to interconnect the tactical and air defense elements of all services including surface and airborne command, control, surveillance and intelligence centers, Navy ships and combat and support aircraft. JTIDS will provide a high degree of interoperability between data collection elements, combat elements and command and control centers within a military theater of operations. Precise signal time-of-arrival measurements, coupled with the transmission of emitter location, are used to generate a common grid coordinate system containing the location of all active net participants. The system uses Time Division Multiple Access (TDMA) to interconnect all system users into one common channel, or network, for distribution of information. Each authorized network element is allocated a dynamic number of transmit time slots within the network reporting cycle as needed for its mission. When not transmitting, each element monitors the transmissions of the other elements and extracts the information as needed. Since the system is nodeless, survivability is enhanced and the system exists as long as two or more elements exist (Reference (4)).

Although the specific potential benefits of JTIDS have not been measured, several generic benefits are available for use in tactical fighters. These are:

- o Jam resistant communications
- o Intercept enhancement
- o Beyond visual range threat identification
- o Supplementary threat warning
- o Relative navigation
- o Blind NAV bombing capability.

JTIDS is a multiphased program which is scheduled to achieve full operational capability by 1984.

A TDMA radio terminal has been built by Hughes and delivered to Boeing for flight test evaluation on a USAF E-3A. Singer-Kearfott is developing terminals suitable for use by F-14, F-15, and F-16. ITT has a contract to develop an advanced terminal. Future developments envisioned include a waveform synthesizer to provide the desired transmissions for JTIDS, IFF, and TACAN. This would allow the JTIDS to assume the IFF function in the JTIDS network as well as remaining capable of interfacing with existing equipment. Current plans are to use frequency hopping spread spectrum techniques to provide ECM protection with no intercept resistance. The use of pseudo random direct sequence generators, using code techniques to enable simultaneous use of time slots along with jam and ECM resistance, are under study.

**3.5.4 AWACS** - The Advanced Airborne Warning and Control System (AWACS) will provide air surveillance capability, command, control and communication functions throughout the U.S. and overseas. Its surveillance radar provides the capability to detect and track aircraft at any altitude over land and water. Data processing, display and communication equipment provide an effective command control facility.

Three exercises were held in 1976 to evaluate the AWACS operational effectiveness. The ability of AWACS to perform surveillance, provide command and control communications, provide survivable command control for continental U.S. defense, and to operate with intensive ground and airborne ECM was evaluated. Reportedly the AWACS equalled or exceeded expectations in all exercises.

The first operational E-3A AWACS aircraft was delivered in March 1977. Currently Congress has approved purchase of 19 AWACS aircraft. The specific functions and utility of the AWACS are classified and therefore not discussed in this report.

**3.5.5 GLOBAL POSITIONING SYSTEM** - The NAVSTAR Global Positioning System (GPS) will provide precise, three-dimensional position and velocity information to aircraft, ships and ground forces. The GPS development is currently in the validation phase, with early results indicating that the system can yield the accuracy anticipated. If full scale development is approved in 1978-79, production should begin in 1982. Eventually 24 satellites would be orbited for full global coverage by 1984.

A GPS receiver would compare the time a signal is transmitted to the time the signal is received in order to determine distance from three or four satellites. By knowing the satellites' positions very accurately, and by accurately determining the transmission time, the user's position can be accurately determined. Basic to this concept is the development of highly accurate and stable atomic clocks suitable for the space environment. Velocity information can be determined by measuring doppler shifts.

Also critical to the GPS concept is the development of the "Type X" receivers to function during high speed dynamics and severe jamming. Mechanizations considered for minimizing jamming are pseudo-random-noise coding, development of a high performance antenna array and addition of three geo-synchronous-orbit satellites (to increase power levels).

The "Type Z" receiver may be introduced as an intermediate step in the full utilization plan for GPS. This receiver would replace the ARN-118 TACAN to provide three-dimensional navigation and position equivalent to or better than current 2-D navigational accuracy. The primary use of this equipment, however, would be for transports.

#### 4. CREW REQUIREMENTS

The primary objective of Task 2 is the generation of Crew Information Requirements, the multitude of data bits that must be displayed in an acceptable form to the crew in every phase of the mission. These information needs were determined for the types of missions and mission requirements determined in Task 1 (shown in Appendices A and B, respectively). The combination of crew requirements and information needs provided the basis for determining the promising display integration options considered in Task 3.

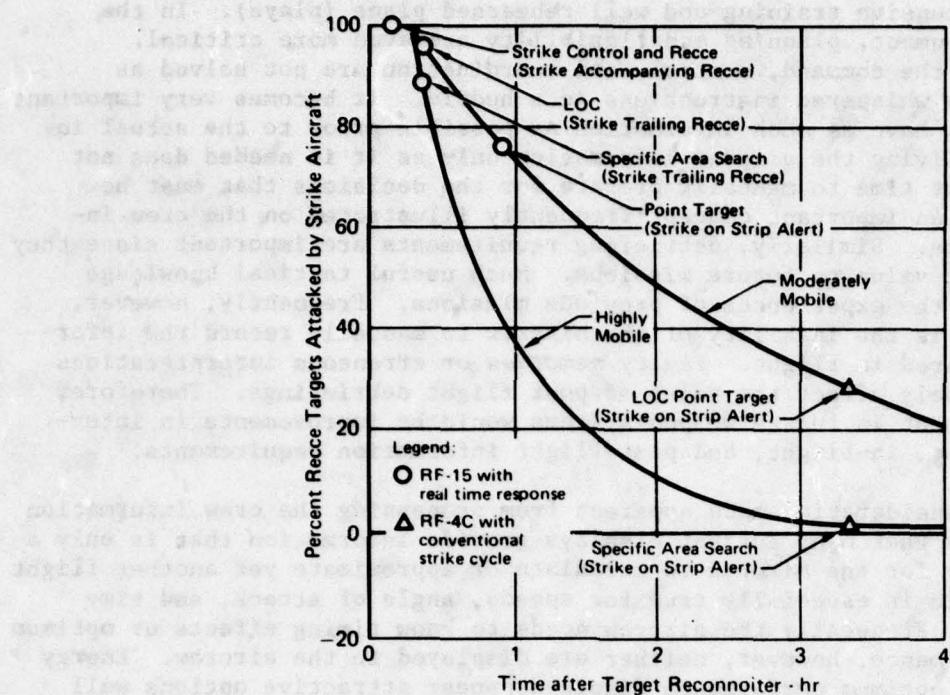
##### 4.1 MISSION LIMITATIONS

A general discussion of combat mission limitations will serve to constrain the problem and focus the subsequent evaluation. The purpose of this discussion is to identify the common or basic limitations that exist throughout TACAIR missions. For the purpose of this study, the basic mission limitations are discussed below:

o Fuel - Historically, fuel is the most important mission planning consideration for fighter type aircraft. Fuel, in conjunction with airspeed and altitude options, determines the maximum effective combat radius, loiter time, and, sometimes, maximum weapons loading. Because of the many variables affecting fuel consumption, a pilot must be constantly aware of his current fuel state and continuously able to estimate future mission and fuel requirements. In many cases this estimate is no more than a "best guess" because of the unpredictable nature of combat missions. In any mission analysis, once an aircraft is airborne, fuel becomes a depleting resource that will frequently become a leading, if not prime consideration in the decisions an aircraft commander makes regarding the conduct of the mission.

o Time - Time can be the most critical factor in accomplishing a specific mission or individual task. However, time is not a physical parameter, per se, affecting performance of an "in-inventory" operational aircraft (in the same manner as stores, drag, etc.). It is recognized that in the aircraft preliminary design phase, task time and operational interaction times can drive the total aircraft design and pilot work load; but, these considerations are outside the scope of this evaluation, considered "given" for the scenario at hand, and will interact with specific mission flight profiles. For example, to defeat enemy bombers it is important to complete the intercept prior to bomber weapons release. A few minutes after weapons release could permit unacceptable damage to friendly forces. If a target is attacked by an integrated strike force, the results may be very dependent on the aircraft arriving together at a specific time and place. The synergistic advantages of a combat mission are frequently dependent on timing.

Some target types are time fatal, i.e., their value decreases as time continues. For example, the position of a truck convoy has been determined. The probability of a strike aircraft locating the target decreases as the time from the last position update increases. This is true for most mobile targets. (See Figure 21.) In some cases, a target's value may increase in



**Figure 21**  
**Time Delay Effect**

a given period, but because the circumstances have changed the target is no longer suitable. Tanks advancing to attack friendly forces are much more attractive targets when in open fields some distance from the friendly positions. Once actively engaged in the close proximity to friendly forces, the entire mission has changed and the aircraft and weapons may no longer be suitable. In this case the mission has changed from Air Interdiction to a difficult Close Air Support Mission. Therefore, in real operations, many things depend on time: response time, time on target, elapsed time, time remaining, etc. In addition, many flight performance factors are measured against a time standard: airspeed (NMPH, MPH, FPS), fuel flow (GPH, PPH), turns (degrees/sec), vertical velocity (FPM), etc. Thus, time, in one form or another, is an important element throughout a mission.

In summary, time and fuel are important mission constraints on all TACAIR missions. A careful evaluation of these fundamentals is necessary when considering crew requirements and information needs, since frequently these considerations will be the deciding factors in the aircravt's decision making process.

A mission can be divided into three major phases: Preflight, In-flight, and Post Flight (see Figure 12). These phases are each important for a variety of reasons, but the in-flight phase traditionally receives the most attention. By examining the crew information needs one can see that much of the information displayed in flight is also needed much earlier, such as in the flight briefing. This requirement can be likened to the huddle of a football team before a play. Imagine the results if the lineup was not

preceded by extensive training and well rehearsed plans (plays). In the tactical environment, planning and flexibility are even more critical. Unfortunately, the command, control, and coordination are not solved as easily as a few whispered instructions in a huddle. It becomes very important that an aircrew have as much information as possible prior to the actual in-flight task. Giving the aircrew information only as it is needed does not allow sufficient time to mentally prepare for the decisions that must be made. This is an important concept frequently illustrated on the crew information charts. Similarly, debriefing requirements are important since they can be of great value to future missions. Much useful tactical knowledge is gained from the experiences of previous missions. Frequently, however, a disadvantage is the inability of the aircrew to manually record the information encountered in flight. Faulty memories or erroneous interpretations can also adversely affect the value of post flight debriefings. Therefore, a real improvement in future weapon systems would be improvements in interfacing preflight, in-flight, and post-flight information requirements.

Another consideration made apparent from processing the crew information requirements is that many current displays provide information that is only a more useful way for the aircrew to calculate or approximate yet another flight parameter. This is especially true for speeds, angle of attack, and time relationships. Frequently the aircrew needs to know timing effects or optimum aircraft performance, however, neither are displayed to the aircrew. Energy management and optimum performance displays appear attractive options well worth further study.

A return to basics may also prove useful in many areas, particularly in regard to the many automatic options being considered for advanced fighter/attack aircraft. For example, it appears that different weapons such as guns, missiles, and bombs, have basic similarities. To be delivered, each requires an aim point and an indication of the weapons envelope. If an aim point is superimposed on the target or target symbol and the weapon is within the allowable release envelope, i.e., within range, g's, or velocity parameters, then the weapon will hit the target for that release condition, provided there are no system errors. Additional information does not significantly help weapons delivery, although some information may help maneuvering just prior to release or immediately thereafter. A look at basic information needs versus current displays could prove extremely interesting and could greatly simplify displays. Such a study could be approached in a method similar to how the crew information requirements were derived, that is, carefully specify the objectives of a display and then determine whether the display meets the requirement. If not, then other options should be considered. One such case uncovered in this study was the lack of a good primary attitude display. Many aircraft today (F-15 and F-16) can easily maneuver in the vertical; however, current displays give confusing indications when an aircraft is going straight up or straight down (controlled or mechanical precession). In addition, a vast majority of pilots will readily confess to having been confused at one time or another because of the attitude display. In any case, as currently implemented, attitude displays are not in keeping with the advances anticipated in future weapon systems.

#### **4.2 AIRCREW FUNCTIONS**

The functions an aircrew must perform in flight vary from manual skills, requiring a high degree of coordination, to decision making tasks involving quick thinking in a high risk environment. In addition, these functions must be skillfully integrated.

For the purpose of this study the Aircrew Functions are divided into two general categories: (1) mission related functions and (2) general or housekeeping functions. The general or housekeeping functions (tasks) are those common to all aircraft regardless of their mission. These categories, summarized in Figure 22, conveniently align with the elements of the mission profiles and mission requirements previously discussed.

Each general category can be further subdivided into detailed functional categories. This is illustrated in Figures 23 and 24. This approach connects the scenario, profiles, mission requirements and functions, and greatly simplifies the complex integration analysis. This categorization of functions is suitable for most analyses, however, it is important to recognize that the mission functions are frequently dependent on the routine or housekeeping functions. For example, communications increase the flexibility of air power in combat; accurate navigation skills are necessary to get to a target area; aircraft control is an important part of air combat. The converse of these relationships is not true: housekeeping functions are not dependent on the mission functions. For example, the lack of weapons, sensors, and command aids do not prevent an aircraft from navigating cross country.

- |  |  |
|--|--|
| o Mission*   | o Housekeeping   |
| <ul style="list-style-type: none"><li>- Detection</li><li>- Location</li><li>- Identification</li><li>- Decision</li><li>- Execution</li><li>- Assessment</li><li>- Formation</li><li>- Threat Warning</li></ul> | <ul style="list-style-type: none"><li>- Navigation</li><li>- Monitor Systems</li><li>- Communications</li><li>- Aircraft Control</li></ul> |

\*These functions were defined under mission requirements.

**Figure 22**  
**Aircrew Functions**

- o Detection
  - Intelligence Report (Preflight)
  - Visual
  - Sensors
- o Location
  - Visual
  - Reference Systems
    - o Correlation
    - o Coordinates
    - o Offsets
- o Identification
  - Visual
  - Sensors
    - o Dependent (Outside Aid)
    - o Independent (Autonomous)
- o Decision
  - Dependent (Outside Advice)
  - Independent
- o Execution
  - Self-contained
  - Aided
- o Assessment
  - Visual
  - Sensors
- o Formation
  - Control
  - Positioning

**Figure 23**  
**Aircrew Functions: Mission**

- o Navigation
  - Self-contained
  - Externally Aides
  - Visual
- o Monitor Systems
  - Normal Operations
  - Malfunctions
- o Communications
  - Transmit
  - Receive
- o Aircraft Control
  - Climb
  - Descents
  - Turns
  - Straight and Level

**Figure 24**  
**Aircrew Functions: Housekeeping**

An extrapolation of the previous logic to design integration tasks encourages a careful consideration of all functions in the demanding combat phases. In the more routine phases of flight, emphasis can be placed on the housekeeping functions.

A further breakdown of an individual function can be used to specify equipment or technology options to accomplish the task. For example:

- o Navigation

- Self-contained

- o INS
- o TERCOM
- o Doppler
- o Air data.

This type of assessment can then focus on the specific aircrew functions and is more suitable for detailed equipment related time line analyses. Such an assessment can also be used in an analysis of crew requirements and crew information needs.

#### 4.3 CREW INFORMATION REQUIREMENTS

In order to identify the crew information needs, each phase of flight previously identified for each TACAIR mission (see Mission Requirements, Appendix B) was evaluated to determine, first, the aircrew requirements (i.e., the tasks an aircrew must perform during the mission) and, second, the displayed information that aids the pilot in performing the mission tasks, such as heading, altitude, etc.

The results of this analysis are shown in matrix format in Figures 25, 26 and 27 for the Close Air Support, Air Interdiction and Counter Air missions, respectively. These tabulations present the information bit as REQUIRED = 1, FREQUENTLY REQUIRED = 2, and ADDITIONAL VALUE = 3.

A review of these detailed tabulations shows the urgent need for display hardware that will permit the crew to select, or be provided automatically at the appropriate time, the bits of information needed at any time during the mission. This strongly suggests the use of multifunction displays over dedicated displays, which have been traditional for many years in previous crew station designs. Even the cathode ray tube, which possesses the inherent capability of presenting almost unlimited bits of data if properly interfaced with a computer, has been utilized primarily as a dedicated display device (radar, TEWS, etc.).

Advancements in computer technology, which has had almost unbelievable developments in the last decade, especially in miniaturization of reliable, high-speed, large-memory airborne computers, have provided the crew station designer with new possibilities for providing crew information. In fact, suddenly the problem may have become one of providing TOO MUCH information. Indeed, that is viewed by MCAIR designers and test pilots as a very real problem to guard against in any crew station display design effort.

		Post-Flight											
		In-Flight											
		Pre-Flight											
Administration													
Formation Call Signs													
Flight Position													
Aircraft Assignment													
Parking Spot													
Spare Procedures													
Aircraft Configuration													
Frequencies													
IFF/SIF Procedures													
Weather													
Regulations													
Airfield Status													
Airfield Description													
Landing Runway													
Runway Length													
Barriers													
Missed Approach Instructions													
Airfield Elevation													
Decision Height													
Parking Area													
Taxi Routes													
Aiming Area													
Dismount Area													
Alternate Airfield													
Time													
Briefing Time													
Station Time													
Start Engine Time													
Flight Check-in Time													
Taxi Time													
Takeoff Time													
Air Refueling Contact Time													
Time on Target													
Time to Climb													
Control Times													
Landing Time													
Rendezvous Time													
Enroute Times													
Time of Day													
Caution and Warning Systems													
Master Caution													
Configuration Warnings													
Operating Limitation Warning													
Primary System Fail													
Fuel Low													
Oxygen Low													
Environmental Control System Warning													
Autopilot Disengaged													
Avionics Malfunctions													
Altitude Low													
Airspeed Low													

Figure 25  
Crew Information Requirements  
Close-Air Support  
counter Air

**Figure 25 (Continued)**  
**Crew Information Requirements**

Post-Flight		In-Flight												
Pre-Flight														
Altitude	3	2	3	2	3	2	2	1	2	2	1	2	3	1
Altitude Above Mean Sea Level	1	1	2	1	2	2	2	2	2	2	1	1	1	1
Altitude Setting	1	1	1	2	2	2	2	2	2	2	1	1	1	1
Command Altitude	2	1	2	1	2	1	1	1	1	1	1	1	1	1
Target Elevation	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Minimum Enroute Safe Altitude	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Terrain Altitude	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Terrain Clearance	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Velocity	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Vertical Velocity	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Rotation Speed	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Takeoff Speed	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Check Speeds	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Climb Speed (Normal)	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Climb Speed (Maximum Performance)	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Maximum Range Cruise	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Maximum Endurance	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Maximum Range Detour	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Approach Speed	3	2	2	2	2	2	2	2	2	2	2	2	2	1
Landing Speed	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Maximum Safe Speed	—	2	2	2	2	2	2	2	2	2	2	2	2	2
Minimum Controllable Speed	—	2	2	2	2	2	2	2	2	2	2	2	2	2
Limitations	—	1	2	2	2	2	2	2	2	2	2	2	2	1
Corner Speed	—	2	2	2	2	2	2	2	2	2	2	2	2	1
True Airspeed	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Angle of Attack (AOA)	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Ground Speed	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Wind Velocity and Direction	2	1	2	2	2	2	2	2	2	2	2	2	2	1
Turn Rate	—	1	2	2	2	2	2	2	2	2	2	2	2	2
Best Rate of Climb	—	1	1	3	3	3	3	3	3	3	3	3	3	3
Best Angle of Climb	—	1	1	3	3	3	3	3	3	3	3	3	3	3
Mach Number	—	1	3	3	3	3	3	3	3	3	3	3	3	3
Selected Speed	—	1	3	3	3	3	3	3	3	3	3	3	3	3
Emergency Airspeeds	—	1	2	2	2	2	2	2	2	2	2	2	2	2
Weapons Release Speeds	—	1	2	2	2	2	2	2	2	2	2	2	2	2
IAS	—	1	2	2	2	2	2	2	2	2	2	2	2	2
Systems	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Fuel Flow	—	2	2	2	3	3	3	3	3	3	3	3	3	1
Fuel Remaining	—	1	1	1	1	1	1	1	1	1	1	1	1	1
Fuel Required to Destination	—	2	2	2	3	3	3	3	3	3	3	3	3	2
Fuel Management	—	—	—	—	—	—	—	—	—	—	—	—	—	2
Hydraulic	—	2	2	2	3	3	3	3	3	3	3	3	3	2
Electrical	—	2	2	2	3	3	3	3	3	3	3	3	3	2
Oxygen	—	2	2	2	3	3	3	3	3	3	3	3	3	2
Engine	—	2	2	2	3	3	3	3	3	3	3	3	3	2

Figure 25 (Continued)  
**Crew Information Requirements**  
*Chemical Support  
 Counter Air*

Post-Flight		In Flight											
Pre-Flight		Penetration Aids		Missile Planning		1.2. Mission Planning		1.3. Start and System Checks		1.4. Armament		1.5. Takeoff	
Pre-Flight		AI Warning		SAM Warning		Threat Avoidance		Disposables Status		ECM Status		ECM Tactic	
1.1. Mission Planning													
1.2. Pre-Flight													
1.3. Start and System Checks													
1.4. Armament													
1.5. Takeoff													
2.1. Climb to Level OH													
2.2. Climb													
2.3. Turn Left													
2.4. Turn Right													
2.5. Coordinate and ARR!													
2.6. Descend and ARR!													
2.7. Penetration and ARR!													
2.8. Descend													
2.9. Descend and ARR!													
2.10. Descend													
2.11. Descend													
2.12. Descend													
2.13. Execute													
2.14. Assessments													
2.15. Termination													
2.16. Errors													
2.17. Clues													
2.18. Results													
2.19. Reasons to Base													
2.20. Results and ARR!													
2.21. Decisions													
2.22. Actions													
2.23. Landing													
2.24. Descent													
2.25. Descent													
2.26. Descent													
2.27. Descent													
2.28. Descent													
2.29. Descent													
2.30. Results and ARR!													
2.31. Decisions													
2.32. Landing													
2.33. Turn Left													
2.34. Turn Right													
2.35. Stream Checks													
2.36. Standard Deviations													
2.37. Post-Flight													
2.38. Descent													
2.39. Descent													
2.40. Descent													
2.41. Descent													
2.42. Descent													
2.43. Descent													
2.44. Descent													
2.45. Descent													
2.46. Descent													
2.47. Descent													
2.48. Descent													
2.49. Descent													
2.50. Descent													
2.51. Descent													
2.52. Descent													
2.53. Descent													
2.54. Descent													
2.55. Descent													
2.56. Descent													
2.57. Descent													
2.58. Descent													
2.59. Descent													
2.60. Descent													
2.61. Descent													
2.62. Descent													
2.63. Descent													

**Legend:**

- Required information
- 2 Frequently required information
- 3 Additional value

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**Figure 25 (Concluded)**  
**Crew Information Requirements**

Pre-Flight		In-Flight		Post-Flight	
Administrative					
Formation Call Signs	1	1	1	1	1
Flight Position	1	1	1	1	1
Aircraft Assignment	1	1	1	1	1
Parking Spot	2	2	2	2	2
Spare Procedures	2	2	2	2	2
Aircraft Configuration	2	2	2	2	2
Frequencies	2	2	2	2	2
IFF/SIF Procedures	2	2	2	2	2
Weather	2	2	2	2	2
Regulations	2	2	2	2	2
Airfield Status	1	1	1	1	1
Airfield Description	1	1	1	1	1
Landing Runway	1	1	1	1	1
Runway Length	1	1	1	1	1
Barriers	1	1	1	1	1
Approaches	2	2	2	2	2
Misled Approach Instructions	1	1	1	1	1
Airfield Elevation	1	1	1	1	1
Decision Height	1	1	1	1	1
Parking Area	1	1	1	1	1
Taxi Routes	1	1	1	1	1
Arming Area	1	1	1	1	1
Decarming Area	1	1	1	1	1
Alternate Airfield	1	1	1	1	1
Time					
Briefing Time	1	1	1	1	1
Station Time	1	1	1	1	1
Start Engine Time	1	1	1	1	1
Flight Check-In Time	1	1	1	1	1
Taxi Time	1	1	1	1	1
Takeoff Time	1	1	1	1	1
Air Refueling Contact Time	1	1	1	1	1
Time on Target	1	1	1	1	1
Time to Climb	1	1	1	1	1
Time to Go	1	1	1	1	1
Control Times	1	1	1	1	1
Landing Time	1	1	1	1	1
Rendezvous Time	1	1	1	1	1
Enroute Times	1	1	1	1	1
Time of Day	1	1	1	1	1
Caution and Warning Systems					
Master Caution	1	1	1	1	1
Configuration Warnings	1	1	1	1	1
Operating Limitation Warning	1	1	1	1	1
Primary Systems Fail	1	1	1	1	1
Fuel Low	1	1	1	1	1
Oxygen Low	1	1	1	1	1
Environmental Control System Warning	1	1	1	1	1
Autopilot Disengaged	2	2	2	2	2
Avionics Malfunctions	2	2	2	2	2
Altitude Low	2	2	2	2	2
Airspeed Low	2	2	2	2	2

**Figure 26**  
**Crew Information Requirements**  
**Air Interdiction**

**Figure 26 (Continued)**  
**Crew Information Requirements**  
**Air Interdiction**

**Figure 26 (Continued)**  
**Crew Information Requirements**  
**Air Interdiction**

		Air Interdiction																							
		Pre-Flight								In-Flight								Post-Flight							
Information Type	Information Item	1		2		3		4		5		6		7		8		9		10					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19					
Penetration Aids																									
AI Warning																									
SAM Warning																									
Threat Avoidance																									
Disposables Status																									
ECM Status																									
ECM Tactics																									
Mutual Support																									
Special Threat																									
Weapon Information																									
Ballistics																									
Weapons Envelope																									
Weapons Ready																									
Weapons Remaining																									
Weapons Impact																									
Weapon Selected																									
Bomb Fall Time/Impact Point																									
Weapons Options Selected																									
Weapons Delivery Selected																									
Air-to-Air Target																									
Range																									
Bearing																									
Overtake																									
Altitude Differential																									
Target Turn Rate																									
Target Attitude																									
Identification																									
Target Attitude																									
In Range																									
Aim Point																									
Breakaway																									
Air-to-Ground Target Acquisition																									
Target Range																									
Target Bearing																									
Positive Target ID																									
Aim Point																									
Break Away (Pullup)																									

1 Required information  
 2 Frequently required information  
 3 Additional value  
 / / / / / Optional information  
 // / / / Not applicable to mission

Legend:  
 1 Required information  
 2 Frequently required information  
 3 Additional value

**Figure 26 (Concluded)**  
**Crew Information Requirements**  
**Air Interdiction**

Pre-Flight		In-Flight												Post-Flight														
		Initial Briefing						Enroute						Arrival						Flight			Arrival			Debriefing		
		Planning			Preparation			Flight			Arrival			Debriefing			Flight			Arrival			Debriefing					
		1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.17	1.18	1.19	1.20	1.21	1.22	1.23	1.24	1.25		
Administrative		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Formation Call Signs		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
Aircraft Position		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
Aircraft Assignment		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
Parking Spot		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
Spare Procedures		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
Aircraft Configuration		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
Frequencies		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
IFF/SIF Procedures		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
Weather		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
Regulations		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
Airfield Status		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
Airfield Description		1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
Landing Runway		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Runway Length		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Barriers		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Approaches		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
Revised Approach Instructions		1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Airfield Elevation		1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Decision Height		1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Parking Area		1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Taxi Routes		1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Arming Area		1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Dearming Area		1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Alternate Airfield		1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Time																												
Briefing Time																												
Station Time																												
Start Engine Time																												
Flight Check-In Time																												
Taxi Time																												
Takeoff Time																												
Air Refueling Contact Time																												
Time on Target																												
Time to Climb																												
Control Times																												
Landing Time																												
Rendezvous Time																												
Enroute Times																												
Time of Day																												
Crew and Warning Systems																												
Master Caution																												
Configuration Warnings																												
Operating Limitation Warning																												
Primary Systems Fail																												
Fuel Low																												
Oxygen Low																												
Environmental Control System Warning																												
Autopilot Disengaged																												
Avionics Malfunctions																												
Altitude Low																												
Airspeed Low																												

**Figure 27**  
**Crew Information Requirements**  
**Counter-Air**  
**Close Air Support**

**Figure 27 (Continued)**  
**Crew Information Requirements**  
**Counter-Air**

## Close Air Support

Pre-Flight		In-Flight												Post-Flight													
		Altitude			Velocity			Climb Speed			Check Speeds			Climb Speed (Normal Performance)			Climb Speed (Maximum Performance)			Vertical Velocity			Terrain Clearance				
		Altitude Above Ground Level (AGL)	3	2	3	1	3	2	2	1	1	1	1	1	1	1	1	2	3	1	3	1	1	1	1	1	1
		Altitude Above Mean Sea Level	2	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Altimeter Setting	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
		Command Altitude																									
		Target Elevation																									
		Minimum Enroute Safe Altitude																									
		Target Altitude																									
		Terrain Clearance																									
		Velocity																									
		Vertical Velocity																									
		Rotation Speed																									
		Takeoff Speed																									
		Climb Speed																									
		Check Speeds																									
		Climb Speed (Normal Performance)																									
		Climb Speed (Maximum Performance)																									
		Vertical Velocity																									
		Terrain Clearance																									
		Systems																									
		Fuel Flow																									
		Fuel Remaining																									
		Fuel Required to Destination																									
		Fuel Management																									
		Hydraulic																									
		Electrical																									
		Oxygen																									
		Engine																									

Figure 27 (Continued)  
Crew Information Requirements

~~Closure Air~~  
Close Air Support

Post-Flight													
In-Flight													
Pre-Flight													
Penetration Area													
AI Warning	2	2	2	2	2	2	2	2	2	2	2	2	2
SAM Warning	2	2	2	2	2	2	2	2	2	2	2	2	2
Threat Avoidance	2	2	2	2	2	2	2	2	2	2	2	2	2
Disposable Status	2	2	2	2	2	2	2	2	2	2	2	2	2
ECM Status	2	2	2	2	2	2	2	2	2	2	2	2	2
ECM Tactics	2	2	2	2	2	2	2	2	2	2	2	2	2
Mutual Support	2	2	2	2	2	2	2	2	2	2	2	2	2
Special Threat	2	2	2	2	2	2	2	2	2	2	2	2	2
Weapons Information													
Ballistics	1	1	1	1	1	1	1	1	1	1	1	1	1
Weapons Envelope	1	1	1	1	1	1	1	1	1	1	1	1	1
Weapons Ready	1	1	1	1	1	1	1	1	1	1	1	1	1
Weapons Release	1	1	1	1	1	1	1	1	1	1	1	1	1
Weapons Remaining	1	1	1	1	1	1	1	1	1	1	1	1	1
Weapons Impact	1	1	1	1	1	1	1	1	1	1	1	1	1
Weapon Selected	1	1	1	1	1	1	1	1	1	1	1	1	1
Bomb Fall Time/Impact Point	1	1	1	1	1	1	1	1	1	1	1	1	1
Weapons Options Selected	1	1	1	1	1	1	1	1	1	1	1	1	1
Weapons Delivery Selected	1	1	1	1	1	1	1	1	1	1	1	1	1
Air-to-Air Target													
Range													
Bearing													
Overtake													
Altitude Differential													
Target Turn Rate													
Target Attitude													
Identification													
Target Altitude													
In Range													
Aim Point													
Breakaway													
Air-to-Ground Target Acquisition													
Target Range													
Target Bearing													
Positive Target ID													
Aim Point													
Break Away (Pullup)													

( ) Optional phrase  
// / / / Not applicable to mission

Legend:  
1 Required information  
2 Frequently required information  
3 Additional value

Figure 27 (Concluded)  
Crew Information Requirements

Counter-Air

Close Air Support

Nevertheless, existing technology will now permit the display of enormous amounts of data to the crews at any given time, whether or not they actually need it. The design problem then becomes one of providing the precise information needed, at the precise time needed, in the precise format needed for assimilation, and in the precise location needed. Suddenly, the display integration problem has become an enormous task for the designer! Mission accomplishment and survivability in the 1985-1990 time period dictates that this job must be done well.

#### 4.4 OBSERVATIONS AND FINDINGS

The following "Observations and Findings" are a result of the development of the crew information requirements. The observation/findings summarize ideas or facts noted in the course of this study task that proved useful in attaining the Task 3 and 4 objectives in conjunction with the mission profiles, mission requirements, and earlier data base.

(a) Time was identified as one of the more important variables in most mission phases. Many instruments measure distances against time in order to give the pilot a device to calculate arrival times at destinations and altitudes. For example, indicated airspeed (IAS) is satisfactory for flying and maneuvering an aircraft; however, true airspeed (TAS) is frequently included in a crew station because this gives the pilot his velocity over the earth, in a no wind condition, regardless of altitude and temperature changes. Mach indicators also give the pilot his speed in nautical miles per minute. Ground speed (GS) evolved because TAS, IAS, and Mach did not compensate for wind effects. In retrospect, these airspeeds were a natural evolution of an attempt to give the pilot a better way to measure the time he must fly to arrive at a destination. Frequently, these speeds were also valuable in helping the pilot fly his aircraft in maneuvering and instrument flight, and they have resulted in many equations that the pilot uses to mentally calculate other information needed to guide his aircraft. It is this "other information" that must be displayed, such as arrival times, lead points in turns, deceleration points.

(b) The principle of management by exception appears to be the logical method of handling a great deal of the aircrew's information needs. From the crew information summaries, it can be seen that a lot of information is required by the pilot. Regardless of format, it is very unlikely that all of this information can be simultaneously displayed in a usable format. In addition, there is no reason to ever display much of the information. For example, an emergency checklist will never be needed unless there is an emergency. Primary systems, such as hydraulics, electrical, and engine systems, need not be monitored unless there is a deviation from normal conditions. Because of the complexity of modern systems, most equipment operating parameters can be better monitored by a computer or built in test. Therefore, the logical approach is to not display the information unless there is a fault, in which case the fault and the proposed corrective action are both displayed. This is the basis of management by exception, i.e., all is well unless advised otherwise. There appears to be many control and display areas where this principal can be usefully employed.

- (c) Energy management displays and systems appear an absolute must. In deriving the crew information needs, it was found that many traditional bits of information were difficult to justify. For example, some current displays simultaneously provide TAS, IAS, GS, Mach, and angle of attack (AOA). The question is which one does the pilot use? The answer is that it depends. All of the speeds are useful for some phase of flight, but only because they allow the pilot a parameter to approximate other information that is not displayed. This "other information" can vary and could be g's available, turn rate, final approach speed for a given gross weight, arrival time, etc. In many flight phases, an "energy" display is needed to give the aircrew a better approximation of his aircraft's capabilities. This was not explored in this study, but should be given consideration in follow-on work.
- (d) The importance of the ground's proximity stood out as an important information requirement. In both the Close Air Support (CAS) and Air Interdiction Missions, the proximity of the ground was rated as a greater need than in the Counter Air mission, which is normally conducted at a higher altitude. Displays and caution devices for terrain avoidance are suggested as firm requirements for all aircraft, including air-to-air aircraft. (MCAIR simulation experience serves as a constant reminder of the disadvantages to those pilots not being properly alerted to potential ground impact situations.)
- (e) The crew information analysis also suggested that information is needed prior to the actual event or phase of flight. This was demonstrated in several ways. First, a lot of information is required in the mission planning phase prior to flight. This mentally prepared the pilot for the job to be done. Secondly, events must be prepared far prior to their actual happening. Frequencies must be changed, courses set, sensors turned on and adjusted. The terminal flight phases are specific areas when anticipation is necessary. In pilot's jargon, "if you're not planning ahead, you're behind the aircraft." One immediately apparent requirement is the necessity to display the information required for the current flight phase plus the phase(s) approaching. This suggests more than one display and possibly sequenced displays or information.
- (f) In keeping with previous comments, "low" and/or "slow" requires more information. In general, this is because the allowances necessary to avoid dangerous or unfavorable events are drastically reduced. For example, there are fewer options available to an aircrew maneuvering very slow near the ground. There are more options and more time to use them when higher or faster, therefore a reduced information display requirement.
- (g) Many routine functions are important not because of their complexity, but because of their frequency (for example, changes in frequencies, IFF codes, course changes, navigation points, etc.). These tasks can compromise maneuvers such as formation and precision navigation tasks, or the tasks themselves may be performed incorrectly when hurried.

(h) Some areas are extremely important and mission critical but not easy to define. Such things as in-flight clearances, procedures, regulations, rules of engagement and pilot techniques are very important, but are not easy to define as a displayed information requirement. Audio inputs, such as from a radio, are also unattractive for a variety of reasons (i.e., jamming, no written record, misunderstandings, compromise, etc.). In view of new command and control systems, such as the Joint Tactical Information Distribution System (JTIDS), careful consideration must be given to the required information and information display. This requires further study.

(i) A more complete integration of the crew station, pilot, and operations and maintenance structure is required. This must include a natural and easily accomplished flow of the pilot through all flight phases with emphasis on mission planning and preflight up to and including post flight and debriefing. There must be a natural continuity. The pilot and the crew station are evolving as the center of many operations and maintenance functions. This may not always be the case in war time conditions, but appears a very real possibility for peace time and routine training requirements under austere budgets.

(j) The mission planning phase requires access to a great deal of information. The routes, frequencies, fuel calculations, plans, etc. that are required in flight evolve from this flight phase. There must be an efficient method of interfacing the briefing room with the crew station. As any experienced pilot will confess, "the mission begins and ends in the briefing room." Similarly there is a great deal of information available to an air-crew in flight, but impossible for him to record manually. Such things as equipment malfunctions, threats encountered, ECM, precise target locations, etc. could be stored electronically and are extremely valuable in debriefing, and subsequently, follow-on or similar missions. The same equipment envisioned also could be used in peace time to enhance training.

(k) Reassurance to the pilot is hard to quantify, but a necessary feature. A pilot will not blindly accept an aircraft unless the critical systems can be tested or monitored for faults prior to their use. In addition, a critical safety of flight system with only single automatic control is unacceptable. Even though systems are progressing towards more and more automatic control, the old question, "What happens if it fails?" must still be answered.

(l) Some systems and subsequent information requirements are complicated by conflicting objectives depending on the flight phase. For example, on-board weapons are designed to inflict damage on an enemy target; however, it is also necessary to protect friendly forces and facilities from inadvertent release of weapons. Therefore, weapons must be lethal but safe. "Dry passes" (no weapons delivered) or "inadvertent releases" (weapon dropped accidentally) must be prevented, and weapon status displays are valuable in this regard.

(m) Auto systems have the desired effect of reducing raw information requirements. Careful consideration must be given to a "design philosophy" that analyzes: How many and what kinds of automatic systems will the pilot accept? An equally important aspect of this question, in view of past experiments is: What kind of false alarm or failure rate will change the answer to the first question? A pilot will accept more if he is guaranteed that a system will never fail; however, even a single failure in a critical phase may deter his further use of the system. This results in a less capable weapon system.

(n) No study or improvement in displays is ever likely to satisfy all of the pilots, all of the time. Therefore, those information needs that cannot be standardized or accepted unanimously by all pilots, should be made pilot selectable. Many tasks related to flying can be accomplished in a variety of ways, i.e., pilot techniques. Frequently, the best way of doing things, and resulting procedures and regulations, are based on pilots who saw a different way of accomplishing the same task. This philosophy is also designed to the "be flexible" policy of the USAF. In addition, future needs can never be altogether anticipated. Therefore, selectable information displays are attractive alternatives.

(o) A "call up" display capability is required as a backup and, also, because some information needs cannot be sequenced automatically. This is apparent from the crew information needs that vary in priority or go from high priority to none at all. There will always be a case where something else is needed because of the difficulty we have projecting situations.

(p) Some of the air-to-air differences in crew information needs occur due to the uncertainties associated with the mission. For example, there is no reason to know target location or type unless there is a high degree of probability that the target will be when and where it was advertised. This is possible for the Air Interdiction class of targets and somewhat with CAS targets; however, it is impracticable with air-to-air targets where the environment is much more dynamic. Therefore, because of less precision associated with air-to-air missions, more flexibility and awareness is required. On the other hand, in Air Interdiction and CAS missions, attacks can be planned and improved by thorough and very detailed planning.

(q) There are many ideas that come to mind from this analysis, however, most of them are well beyond the scope of this study effort and some of them represent major studies in themselves. Some examples are listed to suggest ideas for follow-on work. No effort is made to examine these ideas in depth. Instead, they should be recognized as suggestions coming from this phase of the study.

- (1) The pilot's "knee board," or a modern improvement, appears to be an attractive candidate for interfacing the mission planning through in-flight tasks. An electronic "wrist board" could program in calculator fashion, a wide variety of information useful to the pilot from briefing to debriefing. It could also serve as an interface to the on-board (crew station) computers and visa versa.

- (2) Traditional attitude displays do not display all of the information needed for advanced fighter aircraft. Many attitude displays are confusing when maneuvering in the vertical. Another or an additional display may be necessary for some of the maneuvers envisioned in future aircraft. One option is a 3-D portrayal of aircraft attitude and flight path.
  - (3) Autopilot submodes can greatly reduce pilot workload. Attractive options are:
    - (a) Attitude hold
    - (b) Course select
    - (c) Automatic throttle control
    - (d) Altitude hold
    - (e) Automatic steering in air-to-air and ground weapons delivery
    - (f) Flight path control
    - (g) Programmable profiles.
  - (4) Improved clocks with a variety of timing options, such as time to go to destination, proposed arrival time at destination, time of day, elapsed time, time remaining for fuel on board, time before bingo fuel, etc., would greatly reduce pilot workload and numerous mental calculation prone to error.
  - (5) Programmable (selectable) displays and audio inputs appear to be one of the most exciting options for optimizing crew stations. Let the individual pilot select (or create) his information needs. This would also increase the utility and flexibility of a system over its life time.
  - (6) Standardize weapon delivery formats. Weapons need only to be directed at an aim point (target) and released within the weapons envelope. For ballistic weapons, the envelope is very small and precise for a given release condition. The envelope becomes larger for guided munitions. Weapons should be designed in this regard and computer algorithms developed to implement the displays.
- (r) "Keep it simple" is the guiding design philosophy from a pilot's point of view.

## 5. DISPLAY INTEGRATION OPTIONS

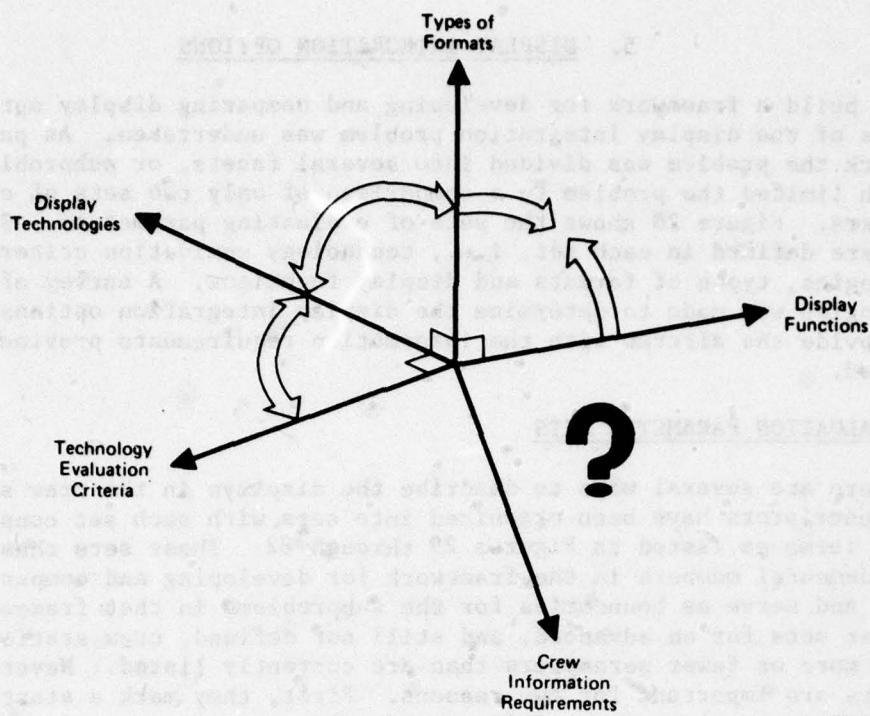
To build a framework for developing and comparing display options, an analysis of the display integration problem was undertaken. As part of that framework the problem was divided into several facets, or subproblems, each of which limited the problem to a comparison of only two sets of evaluating parameters. Figure 28 shows the sets of evaluating parameters. Specific items were defined in each set, i.e., technology evaluation criteria, display technologies, types of formats and display functions. A survey of display technologies was made to determine the display integration options that could best provide the aircrew with the information requirements previously generated.

### 5.1 EVALUATION PARAMETER SETS

There are several ways to describe the displays in the crew station. These descriptors have been organized into sets, with each set consisting of similar items as listed in Figures 29 through 32. These sets thus act as the fundamental members in the framework for developing and comparing display options and serve as boundaries for the subproblems in that framework. The parameter sets for an advanced, and still not defined, crew station may include more or fewer parameters than are currently listed. Nevertheless, the lists are important for two reasons. First, they mark a starting point from which work can evolve. And, second, they provide a means of defining more precisely what is meant by the necessarily general, vague, or abstract set titles thus avoiding ambiguous interpretation and misapplication of the framework to developing display options.

**5.1.1 TECHNOLOGY EVALUATION CRITERIA** - These are a guideline whose application to evaluating a display technology are generally dependent on the type of format being generated. For example, the resolution parameter is a major concern when evaluating a Light Emitting Diode (LED) or Liquid Crystal (LC) used in a matrix format for generating characters, graphics, or full video. But, resolution is of minor concern when LED's or LC's are used in segmented alphanumeric formats. Most of the criteria can be measured with specific units (e.g., cm, W, or  $\mu$ s), but selection of those units is deferred until the criteria are specifically applied. Likewise more detailed descriptors of parameters such as dynamic range, display size, and color are deferred to specific applications.

**5.1.2 DISPLAY TECHNOLOGIES** - Candidate display technologies were surveyed. Results of the survey are presented in Section 5.3. While several of the technologies presented are high risk items for use in the 1985-1990 time period they are listed for completeness and to acknowledge their possible development for operational deployment at a later time. The latter reason is readily rationalized by reviewing the development of plasma, liquid crystals (LC's) and light emitting diodes (LED's) (which are now being placed into operational service) over a comparable time span. The technologies examined are listed in Figure 30.



**Figure 28**  
**Principal Evaluating Parameters**

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- o Brightness
- o Contrast (gray shades - dynamic range)
- o Resolution
- o Maximum display size (number of elements)
- o Color
- o Power requirements
- o Thickness (volume)
- o Weight (density)
- o Environment (g-load, vibrations, temperature range, humidity, ambient illumination, etc.)
- o Aspect viewing limits
- o Time constants (data rates)
- o Storage or refresh requirements
- o Reliability, maintainability
- o Technical status (i.e., operational, prototype, laboratory demonstration, theory)

**Figure 29**  
**Technology Evaluation Criteria**

- o Cathode ray tubes (CRT's)
- o Liquid crystals (LC's)
- o Plasma devices (PLD)
- o Light emitting diodes (LED's)
- o Electroluminescence (EL)
- o Electro/mechanical devices (EMD)
- o Laser displays (LD)

**Figure 30**  
**Display Technologies**

- A - On-off: legend
- B - Alpha numerics: fixed alphabet
- C<sub>1</sub> - Characters (symbols and alpha numerics), raster or matrix generated: variable alphabet
- C<sub>2</sub> - Characters, stroke generated: variable alphabet
- D - Graphics and characters: fixed format and alphabet
- E<sub>1</sub> - Graphics and characters, raster or matrix generated: variable format and alphabet
- E<sub>2</sub> - Graphics and characters, stroke generated: variable format and alphabet
- F - Full video (or fixed image)
- G - Color coding
- H - Size coding
- I - Depth coding
- J - Time coding (typically a software problem)

**Figure 31**  
**Display Format Types**

- o Multipurpose displays (MPD)
- o Moving map display (MMD)
- o Horizontal situation display (HSD)
- o Vertical situation display (VSD)
- o Heads up display (HUD)
- o Helmet mounted display (HMD)
- o Stereo-optic panoramic display (SPD)
- o Dedicated or fixed, instruments and displays (DED's)

**Figure 32**  
**Aircraft Display Functions**

**5.1.3 DISPLAY FORMAT TYPES** - To help determine the applicability of each technology to the crew information requirements, a list was developed of the format types or display coding, that might be used to display those requirements. The types of formats are listed in Figure 31, Items A through F are a summary of the ways in which data can be two dimensionally, or shape, coded. While intensity, or gray shade, coding might be used it is not considered practical except for the full video which does include a range of gray shades randomly selectable on a picture element basis.

The color coding, Item G, could be broken down into discrete colors, continuous color tones and chromatic range limitations. However, since the availability of color is limited and its usefulness, at best, is in dispute, details of color, for each technology, are treated separately. Size coding is the capability to produce different size symbols or image scaling. It requires both a display capability and the software.

The depth, or binocular, coding cannot be achieved by an individual display technology, and the time coding is primarily accomplished with software. While size coding and other monocular techniques can be used to provide depth or range cues, binocular vision cues as obtained from a holographic or stereographic display might also be used by the pilot. Generating a holographic display will require use of a light source, a display technology (e.g., liquid crystals) for the hologram, and optics. A stereographic display requires duplicates of one display technology (to generate the stereopair) and transfer optics. Time coding (e.g., flashing a symbol) is accomplished with the software. However, some display technologies might limit the flashing rate or prevent it (e.g., electro/mechanical or photo-projection devices).

**5.1.4 AIRCRAFT DISPLAY FUNCTIONS** - The display functions are the types of display units that might be used to present visual information to the pilot. The most conventional examples are the dedicated, or fixed, instruments such as the ADI (attitude direction indicator) ball or a clock style altimeter. The more recent developments are the multipurpose display (MPD) or the heads-up display (HUD). The most advanced displays are those such as the stereo-optic panoramic display (SPD) which remain more of a concept than a specific display. The display functions are frequently referred to simply as displays or cockpit displays. A display function might consist of just the display technology (e.g., a CRT) with its inputs to form a VSD (vertical situation display). Or, it might include other technologies (e.g., holographic optics and conventional optics) along with a CRT and its inputs to form a HUD.

**Helmet Mounted Displays (HMD)** - One of the major unresolved problems in designing a cockpit layout is that of panoramic data presentation. How much and which data should be presented, and what panoramic coverage, i.e.,  $30^\circ$ ,  $60^\circ$ ,  $2\pi$  steradians, or  $4\pi$  steradians, is needed? The answer, of course, is mitigated by what capability technology can provide. A current, working answer is the HUD's in use on today's aircraft. Helmet mounted displays are a way to considerably extend the coverage beyond the HUD limits, but HMD's have problems. The extra weight on the helmet is objectionable. They tend to limit peripheral vision. And, their angular aiming accuracy is

considerably poorer than that achievable with a HUD.

The first HMD systems developed used imagery projection from a CRT mounted on the pilot's helmet onto a combining glass. Initially CRT size and performance limited the practical application of HMD systems. Subsequently, very small CRT's ( $\approx$ 1 inch) have been developed which provide high quality video. A disadvantage, in addition to weight, of using a CRT on the helmet is the need for high voltage in close proximity to the pilot. Two different methods have been investigated to alleviate this problem. First, fiber optics can be used to project imagery from a CRT located in the crew station instead of on the helmet. Secondly, solid state media (LED or LCD) can be used to provide a lightweight, low voltage display source.

One example of the solid state display approach is a LED array comprised of 460 matrix points and 21 discretely addressable segments manufactured by Marconi Elliott Avionic Systems. This HMD weighs 6 oz and currently can achieve a brightness of 18,000 ft lamberts (Reference (5)).

Although LED displays are attractive for the display of symbology, their capability to display video is limited by the resolution and shades of gray capability. LCD would be somewhat better but would require a source of light. CRT's mounted somewhere in the cockpit with a fiber optics transmission to the helmet appears to be the most attractive method of displaying sensor video.

Terrain features, threat (both surface and airborne) and attitude data are the most natural to be presented on a HMD. Also, in question is the binocular versus monocular format for HMD's. Due to several factors, to date, there has often been more interest in application of HMD's to rotary wing than to fixed wing aircraft. Some of these factors are: 1) Rotary wing aircraft tend to operate closer to the surface so that properly positioned terrain data is more important. 2) The ranges to targets are less so that weapon miss distances are less susceptible to angular aiming errors. 3) The extra helmet weight is not as significant to the rotary wing pilot as to the fixed wing pilot because the rotary wing g loading is much less. 4) The slower operating speeds and greater maneuverability of rotary wing aircraft require them to react to targets or threats that are further displaced off the velocity vector thus making panoramic data more relevant to their mission success. Two reasons dictate a much closer look at the application of HMD's in advanced aircraft. First, advanced aircraft will probably be much more maneuverable than current models, and second, future attack missions might very likely be operating "in the trees" and with "pop-ups". The result is that advanced aircraft will have motivations for having HMD's that are in common with rotary wing aircraft.

An interim position to using HMD's is to expand the field of view (FOV) of HUD's in aircraft. Moderate FOV increases (to approximately  $20^\circ \times 30^\circ$ ) can be obtained by using diffractive optics in the HUD combining glass. Other techniques for even greater FOV coverage were explored in Reference (6). One technique is to mount additional diffractive combining glasses on the cockpit canopy and use additional image sources to effect a segmented HUD. An alternative is to provide a substrate, internal to the canopy, for

mounting the additional combining glasses. The last method is to use the helmet faceplate as a transmissive, diffraction combining glass and project the display information onto it from projectors in the cockpit. This is contrasted with the more conventional HMD concepts in which the face plate is used as a reflective optical component and the display is projected from a source on the helmet. It was generally concluded that: 1) Mounting combiners on the canopy could conceivably provide a display approximately  $160^\circ \times 80^\circ$  but had many problems to be resolved, 2) Using an internal substitute for the combiners had both assets and liabilities, but further development of the concept was not being recommended, 3) Using the helmet face plate as a transmissive diffraction element was impractical, and 4) Development of more conventional HMD concepts should be pursued.

Stereo-Optic Panoramic Display (SPD) - Display of depth coding requires a display function like the SPD. Unfortunately, the technology has not yet been determined that will simultaneously provide stereo-vision, panoramic viewing, and acceptable physical characteristics. The general approach is to generate an image for each eye, then transfer the image to the appropriate eye through an optics chain, in a manner similar to a dual helmet mounted display (HMD). This approach limits the pilot's peripheral vision. Schemes whereby the image generating devices are fixed (e.g., on the instrument panel) give the pilot peripheral vision but lose the panoramic application of the stereographic data. A holographic display would also provide the binocular depth cues but suffers from similar problems plus the burden that generating the hologram is more difficult than generating the stereopair.

In related MCAIR work the display formats are being developed for SPD that might best provide the necessary crew information under normal operational conditions, including air-to-air and air-to-ground combat conditions. SPD development is based on the principle that man can assimilate information in a fraction of the normal scan time if the information is presented to him in a natural scene. For example, detected targets are presented to the crew in the correct azimuth and elevation while providing relative range in a three-dimensional perspective that provides immediate orientation of all targets. By comparison, existing display functions cause the crew to spend considerable time mentally converting displayed target information to actual location in azimuth and elevation before visually locating the target.

Diffraction Optics - While diffraction optics is not a display function, a brief discussion is presented here to assist in understanding how the technology is applied to display functions such as HUD's or HSD's (horizontal situation display). Diffraction optics devices are being used to extend the capabilities of optical systems. Since the direction of light rays are determined by diffractive, instead of reflective or refractive properties, it is largely independent of the surface shape. Because the lens for diffraction optics is made using holographic recording techniques, this concept is sometimes referred to as holographic optics.

The optics work as a "lens" only over a very narrow spectral bandwidth. Therefore, both the transmission of broad band (ambient) light and reflectance

of the desired (displayed) wavelength can have large values. For example, the Hughes Diffraction Optics HUD has transmittance of 90% and reflectance of 80% (P-43 phosphor).

Potential applications include Helmet Mounted Displays using the visor, increased HUD field of view, and canopy displays. A helmet-mounted holographic display was built by Hughes Aircraft with AMRL funding. The reticle was developed by the Naval Weapons Center at China Lake. A HUD with a 20°V x 35°H instantaneous field of view was built by Hughes Aircraft Company and flight tested on a Swedish Viggen. The canopy projection system is not a mature technology and appears to be beyond the technology cut-off date for this study.

Holographic processes can also be used to store aerial chart information. RCA, in support of the Navy Advanced Integrated Modular Instrumentation System (AIMIS) program developed a Holographic Horizontal Display System. (AIMIS has since evolved into Advanced Integrated Display System (AIDS)). This system consists of a holographic system for the display of multicolor aerial chart information and a rear projected CRT for real time presentation of data. Figure 33 (Reference (7)) summarizes the advantages of this system.

## 5.2 PARAMETER INTERRELATIONSHIPS

The problem facets represented by the large arrows in Figure 28 are only the initial concerns. Due to the very involved nature of the problem each set of parameters is dependent on not just one but all of the other sets to some degree. An example is previously cited in discussion of the technology evaluation criteria. The criteria are also used to evaluate the display functions and the format types even though these interrelationships are not indicated in the figure. In the total problem solution all interrelationships are considered. Analysis relating the displays to the crew requirements has not yet been completed as indicated by the question mark in the figure. The following are examples of how two interrelationships might be used in working the visual displays integration problem.

5.2.1 TECHNOLOGY VS FORMATS - Figure 34 shows a limited list of the display technologies and how they might be applied to achieving each of the various display formats. Figure 34 is an example description of the interface. Several of the items are too dependent on other factors so that a question mark must be used. An example is: whether or not a CRT can provide color coding (format type G) depends on what type colors and display brightness/contrast are required. Thus, a question mark appears in that square. In an actual evaluation these factors would be known so that a yes/no decision could be made. The other formats can or cannot be achieved with reasonable certainty using a CRT.

5.2.2 DISPLAY FUNCTIONS VS FORMATS - Figure 35 gives the relationship of the display format types and the various display function options available. It can be used in either of two ways. First, assuming that the required

#### Map Data

- **Storage Medium**
  - Easily Duplicated
  - Inexpensive
  - High Density
  - High Durability
- **High Brightness (Nonabsorptive Storage Medium)**
  - Common Area Multiple Image Storage
  - Easily Annotated
- **Registration and Address Data**
  - High Redundancy
  - Image Immobility

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**Figure 33**  
**Advantages of Holographic Data Storage**

#### Display Technologies

Display  
Format  
Types  
(See Figure 31)

	LD	EMD	IL	EL	LED	PLD	LC	CRT
A	X	X	X		X	X	X	X
B	X	X	X	X	X	X	X	X
C <sub>1</sub>	X			X	X	X	X	X
C <sub>2</sub>	X							
D	X	X			X	X	X	X
E <sub>1</sub>					X	X	X	X
E <sub>2</sub>	X							X
F	X				?	?	X	X
G	X	X		X	?	?		?
H	X	?		X	X	X	X	X
I								
J	X	?	X	X	X	X	X	X

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**Figure 34**  
**Display Technology Applications**

Display  
Format  
Types  
(See Figure 31)

Display Functions

	MPD	MMD	HSD	VSD	HUD	HMD	SPD	DED's
A	X							X
B	X							X
C <sub>1</sub>	X							
C <sub>2</sub>	X			X	X	X		
D								X
E <sub>1</sub>	X		X					
E <sub>2</sub>	X	X	X	X	X	X	X	
F	X	X		X				
G								X
H		X		X			X	
I					X	X		
J	X	X	X	X	X	X	X	X

Figure 35  
Formats/Functions

format types have been established, it can show which formats are required on each display function. Or, second, assuming that the display functions have been established, it can show the types of formats available on each of the functions. In a crew station development both uses are employed in an iterative fashion until agreement is reached and all the crew information requirements are satisfactorily presented.

### 5.3 DISPLAY TECHNOLOGY EVALUATION

Examples of display technology have been listed in preceding sections of this report. In this section, that list will be expanded and detailed information supplied about each technology or display device. While the evaluation data for each technology is extensive, it is not exhaustive. The data does provide the gamut of evaluation parameters that should be considered for all contending display technologies. The conventional electro-mechanical instruments are not evaluated. However, it must be remembered that they are generally well developed devices with excellent reliability that might still be the best choice for certain functions such as a reserve "get down" capability. Their primary disadvantage is a fixed function which, when all functions are aggregated, results in an overloading of the available instrument panel area. To circumvent panel space limits, advanced aircraft such as the F-18 are using multipurpose displays which are used like an "electronic tablet" to present a variety of information by time sharing panel space. The F-18 display technology, for the multipurpose and other electronic displays, is cathode-ray tubes (CRT).

The CRT has earned a position as the standard electronic display against which other technologies are judged. The CRT image has sufficient brightness/contrast, size, resolution, and format flexibility to satisfy virtually all data display requirements. The only notable exception is a color capability. It has not yet been fully resolved if CRT's can provide color as required in a fighter cockpit. CRT's, however, are not perfect. They occupy a large volume, have a limited reliability, and impose power and weight penalties. Consequently, research has been pursued for decades to find a CRT replacement. Earliest efforts were with electro-luminescent devices. Then plasma, liquid crystal (LC), laser, and light emitting diodes (LED) devices were invented and followed by varying amounts of development. As predicted in an earlier study (Reference 8) the CRT has retained its pre-eminence for displaying a full video format. Also, as speculated, the matrix format technologies (plasmas, LC's, and LED's) have made significant inroads to the display market for alphanumerics and graphics as witnessed by the use of these technologies in a myriad of commercial and military products, including alphanumerics for point of sale equipment (sophisticated cash registers), automobile instruments, hand calculators, watches, electronic laboratory instruments, and full graphic formats with alphanumerics for computer terminals in military field use as well as commercial use. Even a video capability has been demonstrated with LC display panels. Additional technologies such as electrophoretics, magnetic particles and electrostatic particles (Gyricon) have been discovered and might be developed to provide future displays.

Technologies to be employed in future cockpit displays are not readily predicted. Anyone attempting such a prediction, evaluating technologies for applications in future aircraft, or selecting technologies for future development should consider the following items. Since a full video format will probably be required to present pictures obtained with imaging sensors, the image quality generated with a CRT must be retained on at least one display. There is a strong incentive to replace the CRT to reduce maintenance problems and save volume, power and weight. Much of the displayed data will require only a graphics format at most, or perhaps only an alphanumeric format. For this data, it is likely that the solid state, matrix technologies might be used. To date, non-CRT technologies have often been rejected for open cockpits because they lack sufficient brightness to challenge the 10,000 ft L ambience. It should be remembered that both display contrast and brightness affect performance. Thus display technologies with less than a 10K ft L brightness and proper filtering might provide performance as good as a brighter CRT technology.

The following evaluation of individual technologies is oriented toward net performance characteristics. Considerably more detail is available in literature such as the Proceedings of the Society for Information Display or the IEEE Transactions on Electron Devices. Vendor data, while less formal and less state-of-the-art, provides generally reliable data on what is realistically available after all the design tradeoffs and compromises have been made. The data in Reference (8) give an older, tutorial review of several display technologies; and a contemporary overview comparison of displays is given in Reference (9).

**5.3.1 ELECTROLUMINESCENT (EL) DEVICES** - One of the original challengers to CRT supremacy, the EL devices fell out of contention during the early 1970's with the rapid development of the other technologies. Since then, the development and application of thin film transistor technology (TFT) has produced EL displays that are competitive. TFT provides individual picture element storage, thus improving brightness by increasing the active duty cycle. The element storage and TFT addressing characteristics also reduce the matrix addressing problem which has plagued non-CRT display devices. A review of the EL forms, or device applications, is given in Reference (10). In summary, the forms are AC and DC Powder Electroluminescence and AC and DC Thin Film Electroluminescence. The AC thin film EL (TFEL) is receiving most current emphasis. Several companies are investigating TFEL including Rockwell International, IBM (Reference (10)), Aerojet Electro Systems (Reference (11)), Sharp Corporation, Nara Japan (References (12) and (13)), and Westinghouse, (References (14), (15), and (16)). Typical display characteristics are:

**Resolution** - 20 to 50 epi have been built, and work is in progress on 100 to 128 epi units for larger panel displays. Small demonstration displays as CRT replacements in HMD's are being developed with 500 epi.

**Brightness** - 30 ft L. Values as large as 150 to 200 ft L should be available but the question remains as to whether these larger brightness values can be obtained without a life expectancy penalty.

**Contrast** - 10:1 or better. A full video capability has been demonstrated. Use of a black absorbing layer and other filtering techniques reportedly permit viewing even in 10K fed ambience.

**Display Size** - Maximum reported has been approximately 6 inches or 240 by 320 elements. The physically smaller devices being developed for HMD's (see Resolution) are approximately an inch by 1-1/3 inches but contain 485 x 645 total elements - sufficient for all the active elements in a standard 525 line TV frame with 4:3 aspect.

**Color** - Dependent on the phosphor selected, all colors are available so that a full color display is not impossible but would require several years of concentrated effort.

**Power Requirements** - Drive Voltage is in the 100-300v range and efficiencies of 3 l/w have been reported with a future possibility of 10 l/w. Sustaining power for the 240 x 320 element system is reported as 10w.

**Thickness** - Less than one inch, however, edge connectors might give local increases in the profile.

**Weight** - Not determined.

**Environment** - Due to solid state and sealed construction it is rugged and insensitive to temperature.

**Aspect Viewing** - Basically lambertian, like looking at a CRT.

Time Constants - Compatible with standard video rates.

Storage/Refresh - Internal storage provides CRT type brightness and frame "freeze" via the inherent memory.

Reliability/Maintainability - TFT performance of 1000h has been demonstrated and phosphor life times of 10Kh have been demonstrated. It is assumed that the display would be a line replaceable unit (LRU) but unlike a CRT it would not be refurbishable.

Technical Status - Laboratory demonstration models.

5.3.2 LIGHT EMITTING DIODES - Fundamentally LEDs are similar to EL in that they are a solid material that converts applied low frequency electrical energy into visible (or near visible) energy. A difference is that the LEDs are single crystal devices, while EL devices use bulk powders and polycrystalline films. The major application of LEDs has been in segmented alphanumeric character (ANC) displays where they are available on a commercial basis from several suppliers. A list of manufacturers is available in directories such as Reference (17). Performance data is available from the manufacturers or from technical publications such as References (18) and (19). As ANC displays, LEDs are widely used in the industrial and commercial worlds. A second large application of LEDs is as a replacement for incandescent light bulbs. Such design capitalizes on the relative ruggedness and long life of the LEDs. A more formal comparison of LED and light bulb characteristics is found in Reference (20). The practical application is found in References (21) and (22) with Reference (22) citing a LED that is a direct replacement for the T-1 3/4 incandescent bulb.

ANC characters are also available in LED devices using a dot matrix to form the characters. Typically these are 5 x 7 or 7 x 9 arrays. Larger modules, to 30 x 36 arrays, capable of simultaneously displaying multiple ANC are also available. For a 1 x 1 inch module it appears that a practical limit of 70 to 100 elements (LEDs) per row and per column might exist due to accumulating power loss in the row and column leads (Reference (23)). However, modules can be assembled to form larger displays. These module assemblies are available commercially in densities of 30 to 50 elements/inch and sizes as large as 6 x 5 inch with standard sizes of 2 x 4, 2 x 2 and 1 x 1 inches (Reference (24)).

Selective spectral or polarized filtering can be used with LEDs, as with most display devices, to retain adequate contrast in high ambience. A LED dot matrix ANC display employing selective filtering was built and tested, and demonstrated an ability to be effective in ambiences as large as 10K ft<sup>l</sup> (Reference (25)). Conventionally, 10K ft L is considered as the maximum cockpit brightness encountered. The LEDs in Reference (19) are advertised as viewable in bright sunlight. Reference (25) also makes a point about using bright displays - with contrast - when the observer is bright adapted (i.e., high ambience conditions) as opposed to simply supplying a high contrast display, albeit darker, as might be done with a passive (e.g., liquid crystal) display.

A review of LED technology is available in Reference (26). Emphasis is on the red LEDs used in watch and calculator displays, but other emission colors are covered. Cost data and fabrication technology are also presented.

Typical LED display characteristics are:

Resolution - 30-50 epi for dot matrix, properly proportioned segmented characters from 0.3 to 0.8 inches high.

Brightness - up to 1000 ft L.

Contrast - 100:1 in moderate ambient conditions. Useful displays are available even with 10K ft L ambient. Primary applications have been on-off rather than full gray scale required for video.

Display Size - Maximum reported is 6 inches with approximately 200 to 300 elements. Larger sizes and more elements are possible by stacking more modules. Limits are total power consumption and required driving circuits.

Color - Primarily red but green and yellow are available. Work is progressing on blue LEDs (References (27) and (28)). Blue is not available commercially and efficiencies are low compared to other color emissions.

Power Requirements - 1.5 to 2.0v at  $1A/cm^2$  ( $6.5A/in^2$ ) drive current for typical 1000 ft L brightness (400w for a 5 x 6 inch display). Current value determines brightness.

Thickness - Less than one inch and possibly as little as 1/10 inch.

Weight - As little as 1/2 ounce/in<sup>2</sup> excluding drive circuitry.

Environment - Rugged and temperature insensitive (0-70 °C or greater operating temperature range).

Aspect Viewing - Tends to be slightly directional but not a problem for fighter aircraft cockpits (up to 150° viewing angle).

Time Constants - Basically they are compatible with standard video rates.

Storage/Refresh - No inherent storage is provided. Refresh must be frequent enough to avoid flicker.

Reliability/Maintainability - Life time is on the order of 10K to 100K h. The display is considered an LRU and not refurbishable.

Technical Status - Operational.

5.3.3 PLASMA DISPLAYS - Considered by many to be the leading contender for replacing CRTs, plasma displays are being used extensively in commercial and industrial systems and are being introduced to military systems. There are problems though that impede their acceptance into a fighter cockpit. Their

neon orange color is confused with the red warning lights used in cockpits. They have trouble holding up to full sunlight ambient conditions. And, they have not been able to produce a full video compatible to a standard TV format. An excellent summary and review of plasma displays was written by Alan Sobel (Reference 29) and is recommended as a starting point for those seeking further information.

Plasma has been used in segmented character formats and dot-matrix formats. Experimental applications have been made of the dot-matrix to video data presentations, but results are limited. Both dc and ac operation are used. The differences between dc and ac operation are decidedly more pronounced when evaluating the large dot-matrix formats available on devices such as the Burroughs "Self Scan" (Reference (30)) display which is a dc device.

Dc devices because of their self-scan feature (non-self scanning devices have only limited development and none have been commercially successful) require fewer drive circuits than do ac displays. Typically self-scan devices need a driver for each row of picture elements and three drivers for all of the columns. Due to minimum brightness requirements, practical current limits, and the duty factor effect on brightness, 200 columns appears to be a practical maximum. DC devices possess no inherent memory, but they can more easily be adapted to intensity modulation than can ac devices. Ac devices typically have inherent memory which permits bright displays even when the size grows to 512 x 512 or 1024 x 1024 elements. The memory also provides a flickerless, high resolution display for limited bandwidth sources. But the ac device memory makes it difficult to edit or access data on the display, or to generate a movable cursor on the display.

The neon orange color can be replaced with other colors by using phosphor in conjunction with each element or cell. Full color TV displays with limited brightness, fatigue, size and other characteristics have been made to demonstrate the color capability (References (31), (32), and (33)). Filtering can be and often is used on plasma displays to retain contrast in higher ambient conditions but there is no strong concern, by display manufacturers, about increasing brightness since it is sufficient for commercial application and even for a great number of military applications. Plasma displays are rugged and transparent. These characteristics along with sufficient brightness qualifies them for field army use (Reference (34)). Commercial units rugged enough for airborne or shipboard environments are also available (Reference (35)). Several approaches to producing full video displays have been attempted (as noted in References (31), (32), and (33)), but none have had more than limited success. Greater brightness is required to handle the dynamic range in video data. Development of that capability as well as the other requirements for a video display will probably be spurred by interest from consumer TV manufacturers, and development of military applications dependent on greater brightness, etc., will probably have to await successful development of the consumer devices (Reference (29)).

Typical plasma display characteristics are:

Resolution - 30-60 epi for dot-matrix, and properly proportional segmented characters from 0.25 to 6.0 inches high.

Brightness - 30-50 ft L typical to values as great as 360 reported.

Contrast - 20:1 or greater in moderate ambient conditions. Achieving video gray scales is not easy, hence plasma is primarily used as an on-off display.

Display Size - For ac panels, size is almost unlimited (17 x 17 in. panels with 1024 x 1024 elements have been made and sold). DC panels are limited to approximately 200 columns in the horizontal and by the number of driver circuits in the vertical. Units with 40 x 12 character capability (280 x 108 elements) are available.

Color - Primarily neon orange but limited three color or other monochrome colors are available.

Power Requirements - Drive voltage is usually 200 to 300 volts and efficiency is a few tenths of a lumen per watt. Net power including drive circuits is 200-300w.

Thickness - The display panel itself is less than one inch but mounting hardware and electrical drive circuitry can increase the thickness for some models.

Weight - 55 lbs for a complete unit with 8 1/2 x 8 1/2 in. display (includes frame and drive electronics and power supply).

Environment - Rugged and temperature insensitive (operates in -20 to +55 C and 95% RH).

Aspect Viewing - Wide aspect viewing.

Time Constants - DC types can be operated at standard video rates. AC types are available with a worst case vector writing time of 10 ms for 512 points.

Storage/Refresh - DC types have no inherent storage thus need complete refreshment, much like a CRT. AC types have inherent memory for each element.

Reliability/Maintainability - The plasma panel is considered a LRU with reliable operation of 100Kh and the only maintenance is to clean the display face.

Technical Status - Operational.

5.3.4 LIQUID CRYSTAL DEVICES - A major advantage of LC's is their low power consumption which is due to the fact that they emit none of their own radiation but modulate ambient light. They also retain contrast in bright ambient situations but have temperature and angular viewing limitations. There are several LC phenomena that can be used to provide light modulation. Dynamic scattering and nematic field effect are the two most prominent phenomena. An early review of LC phenomena concentrated on the dynamic scattering (Reference (36)) while a later review explains the twisted nematic field effect (Reference (37)). Both reviews (as well as Reference (8)) are good LC tutorial sources.

Because of their low power drain LCs have received broad usage in consumer devices like electric watches and hand calculators. However, to be accepted LC's have had to meet minimum performance standards for temperature and reliability characteristics as well. An example of the design considerations is given in Reference (38). LC's are available commercially in a segmented format for alphanumerics that could be used in a wide variety of equipment (Reference (39)). Dot-matrix formats have been built but must still be considered in the "development" stage. Examples are given in References (40) through (44). Reference (41) is especially interesting when compared with Reference (44). It is apparent that the same TFT technology was used to address display matrix elements of either EL or LC material. This commonality underscores the importance of advances in large scale solid state devices and integrated circuitry techniques to the advancement of large matrix display technology.

LC technology has for most practical considerations solved the temperature limitation problem through materials research or by supplying supplemental heating to the display elements. However, the limitations must still be considered. The problem of limited aspect viewing remains but should not be as significant for a cockpit installation as for many other uses. Life expectancy for dc operated LC's is questionable but for ac operation is up to 20,000 hours. Response times are slower at low temperatures but units working at standard video rates have been demonstrated. To use LC's in a direct viewed cockpit display requires an overhanging light absorbing shield. The shield forms a black background to be "seen" by the pilot via the specular axis. Bright spots, symbols, etc., on the display are generated by incident light (in conjunction with the LC elements) which might include direct sunlight on the display. The shield might cause problems in the cockpit design by protruding into the ejection envelope or possibly occluding other displays. Another criticism of LC's is that they might not be sufficiently bright even though retaining contrast, for certain ambient conditions (References (45) and (46)). Such criticism can be countered by supplying a separate light source for the LC's to supplement the ambient actually reaching the display. The following parameters specify LC performance;

Resolution - 100 epi for the 3.5 inch panel displays. For smaller devices being developed as potential CRT replacements in HMDs, resolutions on the order of 588 epi are reported.

Brightness - Dependent on ambient.

Contrast - 20:1 or better. Both on-off and full video dynamic range have been demonstrated.

Display Size - Units as large as 350 x 350 elements have been made (4 units butted together, each composed of 175 x 175 elements, on 1.75 x 1.75 inches). The LCD being developed as a CRT replacement in a HMD is slightly larger than an inch and has on the order of 600 x 800 elements.

Color - Contrasting colors (as opposed to black-white) using color filters are available for the on-off devices (Reference 47)). Simultaneous display of blue, green, yellow, magenta and white (with gray scale) has been achieved in a projection device using an LC for a light valve (Reference (48)).

Power Requirements - 5 w/cm<sup>2</sup> to 1.0 mw/cm<sup>2</sup> at 3-15 volts.

Thickness - Less than one inch.

Weight - Not determined but is approximately the same as EL, LED and plasma technologies.

Environment - Not quite as rugged as other devices but probably sufficiently rugged for cockpit use. Response times increase with decreasing temperatures.

Aspect Viewing - There are angular considerations that can be quite severe (Reference (49)) but they can probably be handled for a cockpit installation.

Time Constants - 10-500 ms. With a solid state scan converter these rates are fast enough for video data. Also the warmer displays operate with the faster times.

Storage Refresh - Some limited inherent storage is available (each element acts like a leaky capacitor) and mixtures of nematic-cholesteric material provide storage.

Reliability/Maintainability - Up to 20,000 hours with ac driven devices. Dc driven devices have had shorter life times reported. LC are considered LRU's so that only display face cleaning is needed.

Technical Status - Segmented alphanumerics are operational, and video matrix displays are laboratory demonstrators.

5.3.5 CATHODE-RAY TUBES - CRT's are the "standard" because of the versatility, efficiency, low cost and availability. They do have limitations, however. The shadow mask tube, and its variations, provides good color images, however, it has not been ruggedized sufficiently for airborne applications. Consequently, color has depended on phosphor penetration (also called beam penetration) type CRT systems. Phosphor penetration systems might hold up to bright ambience but require spectral filtering to retain contrast. The ruggedness of airborne CRT displays is a questionable item with mean time between failure (MTBF) values ranging from 17 hours to 15,000 hours (Reference (50)). Typical MTBF numbers for fighter aircraft CRT displays are several hundred hours.

CRT displays do occupy significant volume. Volume and weight reduction are always goals sought in a fighter design, but the density for CRTs is not much different than for other avionics (approximately 50 lb/ft<sup>2</sup>). Unless more "efficient" designs are developed, "flat panel" technologies might require as much total weight and volume as CRTs. Only the distribution might be different. Generally the volume requirements are not too critical behind the instrument panel (there are significant exceptions such as the area immediately below the HUD (heads up display)), but instrument panel area is critical. While CRT displays can be mounted in very close edge-to-edge proximity, flat panel displays have edge connectors which occupy important instrument panel area. The significance of these facts remains to be established in light of system considerations, such as how much data will be put on helmet mounted displays

and how much data will be simultaneously displayed on the instrument panel (as opposed to time sharing the displays). There is also some work directed toward using the cathodoluminescence of CRTs in a flat configuration "vacuum tube" device that eliminates the bulkiness of CRTs but retains many of the image producing capabilities (References (51) and (52)). Parameters given in the following listing are for a CRT used as a rather large head-down display; however, technology exists for the production of miniature CRTs that can be used as helmet mounted displays. These, typically, could have a 0.8 inch diagonal dimension, weigh less than a pound, and still have a limiting resolution of 1600 elements (or TV lines).

Typical CRT performance factors are:

Resolution - 120-200 epi

Brightness - 30 - 100 ft L average, peaks to 1000 ft L.

Contrast - 8:1 with 10,000 ft L diffused ambient full gray scale capability for video. With more moderate ambients, contrast is 20:1 or better.

Display Size - 480 to 830 elements on displays that range from a few inches to a 25-inch diagonal.

Color - Almost any monochrome color but yellow-green is preferred. Discrete colors (phosphor penetration) for airborne displays and a full color capability for commercial uses (shadow mask tube).

Power Requirements - 100w for the total display including power supplies. Internally high voltages of 20K to 25K volts are generated but the unit operates from standard 110 vac power.

Thickness - Approximately 12 to 18 inches, dependent on the display size and deflection angle used on the CRT.

Weight - 50 lb but dependent on size used.

Environment - Rugged and temperature insensitive, has been used in fighter aircraft cockpits and met military testing.

Aspect Viewing - Wide aspect, basically a lambertian emission pattern.

Time Constants - Normally operates with bandwidths of 3 - 10 MHz and standard video frame rates. Special units are available with bandwidth capabilities to several tens of megahertz to 100 MHz.

Storage/Refresh - While storage type CRTs are available, basically only non-storage tubes are being considered. A slight "storage" exists because of the phosphor persistence but this only serves to produce greater brightness rather than act as a time storage element.

**Reliability/Maintainability** - CRTs can be very reliable when the display system is properly designed. However, airborne systems usually could stand an improvement in reliability. While CRTs can be refurbished it would be done at a depot or manufacturer level, and they are considered an LRU for field maintenance.

**Technical Status** - operational.

**5.3.6 ELECTROPHORETIC DISPLAYS** - As a passive display device using ambient illumination, EPIDs (electrophoretic image displays) might compete in the future with LCs. The basic EPID concept is charged pigment particles in a highly stable colloidal suspension of a nonaqueous dyed liquid of contrasting color. The displayed data is controlled by applying an electric field via electrodes sandwiching the suspending liquid. The charged particles are moved to the front or back of the field. If the particles are moved to the front they determine the corresponding display element color, or reflected brightness. If the particles are moved to the back, the optical characteristics of the dyed suspending liquid determine the elemental color, or reflected brightness. Gray scale, or color shifts, can be obtained by using a field strength between the extreme values. Usually it is assumed that at least several particles comprise a display element.

Advantages of an EPID are as follows. It has a near lambertian viewing. The switching voltage is modest (15-50 volts). Power consumption is low ( $5\mu\text{w}/\text{cm}^2$ ). Resolution is good (approximately 120 epi). It can be used over a wide variety of sizes (1 in<sup>2</sup> to matrix addressing limits). It is operable over a wide temperature range (-60° to 70°C). It has inherent memory long enough for fighter cockpit application.

Disadvantages are as follows. The life time of EPIDs is questionable. Migration and accumulation of the pigment particles outside the effective electrode areas tends to reduce contrast after many ( $10^8$ ) operation cycles but techniques are being developed to relieve this problem. Also stability of the colloidal suspension is a problem.

While there is insufficient data for typical characteristics as provided for the other technologies the preceding information provides a cursory look at the status of EPID. More data is available through References (53), (54) and (55).

**5.3.7 MAGNETIC PARTICLES DISPLAY** - Like EPID's and LC's, magnetic particles display (MPD) operate by reflecting ambient light. Small magnetic spherical particles are imbedded, or encapsulated, in a binder material. Wax, plastic or other binder material can be used depending on rigidity and optical properties required. Each particle is black on one hemisphere and silvered, or white coated, on the other hemisphere. All particles have the same orientation of silvered hemispheres to their magnetic polarity and are free to rotate, but not migrate, within the binder material. By applying an appropriate magnetic field to each image element that element will appear white, black, or an interim gray shade due to the resulting degree of rotation of the particles within the picture element. Like photographic film grains, MPD assumes several

particles per resolution element (Reference (56)). It is also hypothesized that colored displays could be formed by coating segments of the particles with colors, but control of such a scheme is tenuous (Reference (57)).

Features of MPD's include the following. They are a flat panel (less than one inch) technology. Image parameters include resolution as good as 200  $\mu\text{m}$  spot size (approximately 130 particles per spot size), or 250,000 elements per picture (TV compatible), contrast up to 40:1 with continuous gray scale, and switching speeds suitable for video rates. Driving voltage and power are on the order of 2V and 1/4w for a 9 x 12 cm (3-1/2 x 4-3/4 inch) display, respectively. The device has inherent memory and can be operated over a wide temperature range. Its susceptibility to shock and vibration is not established, but it is described as mechanically rugged. Cost is expected to be low. While no specific data on life, or MTBF, is available, it is reasonably considered not to be a significant problem. MPDs are in the laboratory, prototype development state. More data is available from References (56) and (57).

5.3.8 GYRICON - In effect this display technique is much like the MPD just described with one major exception. Instead of using magnetic particles, Gyricon uses particles (or balls) that have an effective electrical charge, oriented with respect to the reflecting/absorbing hemispheres, and reflectivity control of each resolution element is obtained by applying an appropriate electrical, rather than magnetic, field to that element (Reference (58)). Studies with demonstration Gyricon units indicate the switching times are compatible with video frame rates for control voltages less than 30v. Power consumption is limited to the capacitive displacement current required to switch the balls comprising each element. Contrast has only been 3:1 but improvements are expected. The device has inherent storage. The fabrication and device materials are different than those for the MPD even though the functional operations are similar. The Gyricon is in a laboratory prototype development stage.

5.3.9 LASER DISPLAYS - Seven to ten years ago when lasers were often referred to as "an answer looking for a question," laser displays were considered as a replacement for CRT's (Reference (8)). Studies of deflection and modulation devices and techniques (References (59) and (60)) were being conducted, and there was considerable interest in their application. Since then interest has waned due to low overall efficiency, including inefficient deflection and intensity modulation devices, and the large deflection volumes required. The generally decreasing interest in laser displays has been dramatized by the rise of LED, plasma and LC technology and their applications in the consumer/industrial market. Countering the trend a recent article (Reference (61)) indicates some current interest in using a laser display for the HUD in the Navy's Advanced Integrated Display System (AIDS). Laser displays might be considered if good full video color is needed in a cockpit display but they would probably have a significant cost in required power and volume.

5.3.10 ELECTROCHROMICS - Electrochromics operate by changing the opaqueness of an inorganic liquid by means of a voltage induced chemical change. One method of accomplishing this is by producing a colored, insoluble film on a metallic conductor immersed in the liquid.

Electrochromics offer potential for good contrast, long lifetimes and low operating voltages. However, they are slow and are difficult to matrix into any size larger than 2 in. x 2 in. This is a very undeveloped technology that might eventually outperform LC's. More information is available in References (62) and (63).

#### 5.4 SUMMARY OF DISPLAY TECHNOLOGIES

Figure 36 presents, in matrix format, a summary of the display technologies considered in this study as candidates for cockpit display utilization in the 1985-1990 time period. The parameters used for evaluation are listed in the left column. It must be remembered that the data given is necessarily a summary and might not accurately represent all parameters when more than one is being considered. For example; the weight parameter would deviate depending on the display size selected; the availability of any item such as color might alter the status; or brightness might change the contrast which in turn might be dependent on the resolution. Also, due to the lack of generalizable data a comparison of technologies across a single parameter should be treated with care. For example, the power requirements for EL and LED's do not include power for required drive circuits so that total power might be comparable to or greater than the power for a plasma panel or a CRT. Contrast improvements can be obtained with spectral, or other type, filters with some display technologies. However, not all filtering techniques lend themselves to all display technologies and some contrast values already assume the incorporation of filtering.

The CRT is the fundamental display technology. Other technologies that could find specific applications in the aircraft are plasma devices, electro-luminescent (EL) devices, light emitting diodes (LED), and liquid crystals (LC). There are also technologies that are only in the laboratory demonstration phase that offer long term possibilities. These are electrophoretic displays, magnetic particles displays, the Gyricon and electrochromatic displays, all of which are passive - that is they only reflect light rather than emit their own light. As passive devices these options would be more in competition with LCs than with the other promising options. However, if they were to supersede LCs with enough margin they might eventually even replace CRTs.

When evaluating displays, parameters such as in Figure 31 certainly need to be listed and compared, but the formats and information requirements need also to be considered. The Pilot's information requirements establish what kind of data he needs. These needs must be translated into the display formats required. The types of formats include simple alphanumeric, symbols, graphics, and full gray scale video. Consideration should also be given to whether, or not, the characters are to be generated with a dot matrix or a segmented format. Using color as a coding parameter can help to declutter saturated displays or direct the pilot's attention to particular display items. Although the esthetic value of color displays is well established, the improvements in crew performance using color as a coding dimension has not been consistently demonstrated. However, if one takes into account the purpose of display and the conditions under which it is to be used, more definitive conclusions can be reached. Christ, Reference (64) has shown that

color is most effective in situations where the subject must deal with complex, multiple stimulus formats and when he must distinguish one class of stimuli from another. Potential benefits include improved aircrew efficiency, reduced operator fatigue and reduced training requirements, Reference (65).

PARAMETER	PLASMA PANEL	ELECTROLUMINESCENCE (THIN FILM)	LIGHT EMITTING DIODES	LIQUID CRYSTAL	CRT
Resolution	30-60 epi	20-50 epi, large panels 500 epi, small panels	30-50 epi	100 epi, large panels 588 epi, small panels	120-1600 epi
Brightness	>30-50 ft L	>30 ft L	>100 ft L	Ambient Dependent	>30-1000 ft L
Contrast	>20:1 Binary	>10:1 Full Video	100:1	20:1 Full Video	20:1 Full Video
Display Size	<1024 elements 17 inch sq (ac driven)	240 elements, 6 inch 500 elements, 1 inch	250 elements, 6 in. sq.	350 elements, 3.5 in. 600 elements, 1 in.	480-830 elements 1-25 inch sq.
Color	Primarily Neon Orange Full Color Possible	Phosphor Dependent Full Color Possible	Red; green and yellow also available	Primary Black/White but Contrasting Colors are Available	Phosphor Dependent, Discrete Colors Also
Power Requirements	200-300W	10W	1.5-2.0W/cm <sup>2</sup> 01.5-2.0 volts	5uW/cm <sup>2</sup> to 1.0 mW/cm <sup>2</sup> @3-15 volts	100 Watts
Thickness	<1 inch	<1 inch	<1 inch	<1 inch	=12-18 inch
Weight	50 lbs	-	-	-	Up to 50 Lbs.
Environment	Rugged	Rugged	Rugged	Rugged but Tempera-ture Limits	Ruggedized
Aspect Viewing	Wide Aspect	Uniform, Wide Aspect	Slight Gain But Basically Uniform	Restricted	Uniform Wide
Time Constants	Std. Video (dc driven)	Compatible With Std. Video	Compatible With Std. Video	10-500 ms (with scan converter LC can display std. video)	3-10MHz Std. Video
Storage/ Refresh	yes (ac driven) no (dc driven)	Yes, but is config- uration dependent	No	Limited Storage	None (storage CRTs are available)
Reliability/ Maintainability	100,000 hrs LRU	1,000 to 10,000 hrs, LRU	10,000 to 100,000 hrs, LRU	20,000 hrs, LRU	15 to 15,000 hrs, LRU
Status	Operational/ Commercially Available	Laboratory Demonstra-tion Models	Commercially Available/ Operational	Operational/Labor- atory Demonstration Models	Operational

**Figure 36**  
**Display Technology Comparisons**

### **5.5 SELECTED DISPLAY INTEGRATION OPTIONS**

Display options were selected for their inherent capabilities and in the order in which it appears they will be available to accomplish the desired task (presenting crew information rapidly and efficiently with minimum workload) during the 1985 - 1990 time period. They are:

5.5.1 OPTION 1 - The cathode ray tube, black and white, or color, is considered the first selection, and the standard for comparison, because of the versatility of data that can be displayed with a full video format. It is expected that the CRT will retain its preeminence into the 1985-1990 time period.

5.5.2 OPTION 2 - The plasma flat display panel is the leading contender to replace the CRT in the near term (0 to 5 years) because of the rapid progress made with these units in commercial applications and the fact that they are commercially available.

5.5.3 OPTION 3 - Liquid crystal displays (LCD), while presented as the second choice to replace a CRT, may in fact become the first military cockpit replacement for a CRT as a result of the momentum generated by military funding of liquid crystal display development. Such spending is justified because LCDs have a low power drain and retain good contrast in a large ambience. LCDs for video or graphics, however, are not as mature, in the sense of commercial availability, as are plasma displays.

5.5.4 OPTION 4 - Electroluminescence displays, with thin-film-transistor (TFT) picture elements, although considered speculative, are selected as a long-term replacement for the CRT.

The CRT does such a good job for general applications (e.g., HUD's vertical situation displays (VSD), horizontal situation displays (HSD), etc.) that one might question why we attempt to replace it. Basically, the answer is we need to reduce the volume, weight and power required by CRTs. The technology most nearly ready to replace the CRT is the plasma display. But it too has unique problems. It has difficulty presenting gray scale. The typical neon orange color is not always acceptable. And, it cannot retain contrast in full sunlight. Nevertheless, over 200,000 units have been sold chiefly as computer terminals with a graphics capability. Often gray scale is added to these terminals by software that generates gray scale using schemes analogous to half-tones in printing.

Liquid crystal displays require minimal power and retain contrast in bright environments. They also may require supplemental illumination if the bright environment is not incident on the display (i.e., brightness as well as contrast is required when the eyes are bright adapted) or if the ambient conditions are too dark. Supplemental heating is usually required and viewing angle is often restricted.

For longer term speculation an EL device with thin-film-transistor (TFT) picture element addressing and control is selected to replace the CRT. The choice is speculative and open to dissenting opinions. The rationale for these conclusions follows: The primary advantage of the plasma display is its commercial availability which reflects a rather good state of development for the technology. The liability of plasma being used as a CRT replacement is its difficulty with generating video. LCDs are not as mature as plasma displays but seem to be the pick of military planners. LCDs require less power than EL-TFT devices but have similar problems in addressing and drive circuitry as EL-TFT, both of which have no fewer, perhaps even more, problems than the plasma displays. The EL-TFT devices are in the beginning of their development.

Their major asset is the efficiency with which their phosphor converts input power to radiated lumens. EL is an active display device so it maintains image brightness thus providing a display easily viewed by an eye adapted to a bright ambient. Filtering techniques applicable to EL-TFT devices permit them to retain contrast even in bright ambience. And, EL-TFT devices are viewable over large aspect angles.

## 6. EVALUATION FRAMEWORK

The evaluation framework, for a follow-on study, will incorporate systematic testing techniques as visual display integration concepts proceed through the developmental milestones of predesign, initial design, prototype production, and design verification. Experience gained in past evaluations of design concepts indicates that this approach of progressive evaluation acts as an efficient culling process in determining the feasible as well as the prohibiting factors of a design.

The screening process in this study was accomplished through an informal judgmental process. This process has resulted in the selection of candidate display technologies which showed promising compatibility with the display integration concepts of the near future. The evaluation framework in the follow-on study proposes that the candidates be evaluated comparatively by using a combination of techniques such as trade studies, subjective ratings, mockup evaluations, part-task studies, abstract simulation, and man-in-the-loop simulation.

### 6.1 TRADE STUDY PROCESS

At the termination of this study, some of the candidates may still be in the development stage with limited demonstration capability for crew station application. Most of the descriptive materials presenting design definitions were formulated from a research of published technical documentation. The evaluation technique most suitable for the development stage (possibly pre-design) in a follow-on is the trade study. The trade study process is generally accomplished in a formal subjective manner. The concept alternatives are described in a data package complete with such data as weights, volume occupied, power requirements, reliability, maintainability, safety. Weighting factors are assigned to the different parameters by some combination of engineer, management, and user decisions. The weighting factors are then combined with the parameter values and a total value is derived for each of the alternatives. The higher the figure of merit thus derived, the more favored the alternative. In summary, the steps required to accomplish a trade study are:

- (1) Establish evaluation criteria
- (2) Develop data packages
- (3) Assign weights to the parameters in the evaluation criteria
- (4) Assign values to each of the parameters for all alternatives
- (5) Compute a figure of merit for each alternative.

The evaluation criteria (Step (1)) will consider engineering design parameters as well as human performance parameters. What is of direct interest to the engineer may be of indirect interest to the user, in this case, the pilot. Some parameters, of course, are of common interest to the engineer and the pilot. Suggested evaluation parameters are those discussed in Section 5 plus the following:

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RESEARCH ON VISUAL DISPLAY INTEGRATION FOR ADVANCED FIGHTER AIR--ETC(U)  
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- o Cost
- o Mission Effectiveness
- o Development Risk
- o AGE Requirements
- o Pilot Acceptability
- o Growth Potential

The assembly of the data package (Step (2)) is an engineering function, and data package components will consist primarily of comprehensive information on each of the evaluation parameters, sufficient for the evaluator to assign judgmental values to each concept alternative.

The assignment of parameter weights and parameter values (Steps (3) and (4)) constitute a major activity of the evaluator. The evaluators will be drawn from the population of design engineers, human factors specialists, and pilots. Numerical points assigned to each evaluation parameter provide information on the relative importance of evaluation parameters and magnitude of preference of one alternative over another. For example, if cost, pilot acceptability and maintainability were assigned weighting factors of 40, 20 and 10 points respectively out of 100 possible, the weights indicate that the evaluators view the pilot acceptability factor to be more important than maintainability and less important than the cost factor. In a similar manner, preference ratings assigned to each parameter concept alternative, say, on a scale of 1 to 7, would indicate order of preference for the concepts under evaluation. The figure of merit (Step (5)) is derived by combining the rating values and weighting factors. Possible approaches are multiplication of rating values and weighting factors, or proportion of rating value assigned multiplied by the weighting factor.

Since all the parameters in the evaluation criteria will seldom have the same units of measurement, all data are converted to ratios of best to worse or some common dimension of goodness. Some typical methods of combining such normalized values and weighting factors are given in Figure 37.

## 6.2 SUBJECTIVE RATING TECHNIQUES

When the concept is in the design stage or beyond, drawings, schematics, and, possibly, a non-functional mockup are available. Either informal subjective or formal subjective evaluation techniques are appropriate. The informal subjective technique can be approached by open-ended review of drawings and schematics accomplished by a panel of experts, where comments cover all facets of the design. The formal subjective method is best handled by a carefully constructed paper and pencil exercise. There are many variations to informal-formal subjective technique, and any selection would be highly influenced by the level and amount of design information involved. If a static mockup is available, samples of alternate concept products can be presented to the evaluator for rating on a scale of acceptability. A sample rating form is shown in Figure 38.

Method	Description of Method	Example						
		Normalized Values		Matrix Entries				
		Base	A	B	WF	Base	A	B
1	Ratio Best to Worse if Low is Good, or Worst to Better if High is Good; Multiply by WF	$\frac{400}{450} = 0.89$	$\frac{400}{400} = 1.00$	$\frac{400}{600} = 0.67$	20	17.8	20	13.4
2	Ratio Smallest to Larger and Assign + if Low is Good, - if High is Good; Multiply by WF	+0.89	+1.00	+0.67	20	+17.8	+20	+13.4
3	Base (or A, or B) Value Divided by (Base + A + B) if High is Good; Reciprocals Used if Low is Good; Apportion WF Among Alternatives	$\frac{1/450}{1/400 + 1/450 + 1/600} = 0.349$	0.397	0.27	20	0.34 × 20 = 6.8	7.8	5.4
4	Ratio Alternatives to Baseline Value if High is Good; Ratio Baseline to Alternative if Low is Good; Multiply by WF	$\frac{450}{450} = 1.00$	$\frac{450}{400} = 1.13$	$\frac{450}{600} = 0.75$	20	20.00	22.60	15.00
5	Ratio Alternatives to Baseline; Assign + if High is Good and - if Low is Good; Multiply by WF	$\frac{450}{450} = -1.00$	$\frac{400}{450} = -0.89$	$\frac{800}{450} = -1.33$	20	-20.00	-17.80	-26.60
6	Rank Order the Designs Best = 1, Middle = 2, Worst = 3; Best Earnings $\frac{WF}{1}$ , Middle Earnings $\frac{WF}{2}$ , Worst Earnings $\frac{WF}{3}$	2	1	3	20	10.00	20.00	6.67
7	Find Best and Worst; Scale to Worst = 0, Best = 1, Middle Accordingly; Multiply by WF	0.75	1.00	0	20	15.00	20.00	0
8	Same as Method 7, but WF Apportioned among Alternatives	0.75	1.00	0	20	$\frac{0.75}{1.75} \times 20 = 8.57$	$\frac{1.00}{1.75} \times 20 = 11.43$	0
9	Subjective Scaling of Alternatives, e.g., 400 Watts is Worth 10, 450 Watts is Called 9, 600 Watts is Called 5, Multiply by WF	9.00	10.00	5.00	20	18.00	20.00	10.00

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**Figure 37**  
**Methods of Deriving Trade Study Matrix Entries**  
 (From Lintz, L., Askren, W. and Lott, W., Reference 66)

Mission Scenario Under Evaluation

How Do You Rate the Visual Displays in Terms of:	Visual Display Systems				
	HUD	MMD1	MMD2	HSD	VSD
1. Locating information					
2. Reading information					
3. Interpreting symbols					
19. Information Processing Workload (interpreting, integrating, recalling)					
20. Visual Workload as a function of displayed information					

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Figure 38  
Visual Display Evaluation Form

### 6.3 FUNCTIONAL MOCK-UP EVALUATION

Where the design details have been sufficiently finalized, a functional mockup can be fabricated for use in testing and evaluation. The functional mockup, if interfaced with adequate recording devices, permits the first opportunity for collection of empirical data. Two evaluation techniques, frequently used and highly successful, are discussed in the following paragraphs. These are part-task experimental designs and abstract simulations.

**6.3.1 PART-TASK STUDIES** - Part-task experimental designs are specially structured to measure selected facets of a concept. In the area of visual performance, such studies can be designed to assess effects of coding type, display density, memory load, display patterns, time sharing, and speed stress on human operator performance. Typical criterion measures are reaction time and error rate. A major consideration in constructing such experiments is providing adequate control mechanisms so that the variable selected for testing is measured during the conduct of the experiment relatively free of extraneous variable effects. Factorial designs with repeated measures are particularly applicable. For example, in a factorial design one can study the effects of coding and display density on operator performance, by combining coding and density in various test combinations. Such an approach would yield findings to identify performance effects due to coding independent of display density, display density independent of coding, and the interaction of coding and display density. Speed stress has been a viable variable for testing, and would appear more importantly so, as displays become more integrated. To attain some degree of confidence that the amount of information per unit time is not beyond the processing capabilities of the operator, information input rates can be varied and performance effects measured. Again, a factorial design would be appropriate.

Source of Variance	dF	MS	F
Density (D)	4	5.241	122.31**
Number of Colors (C)	9	1.298	30.32**
D x C	36	0.111	2.40*
Subjects	19	0.103	
Residual	931	0.043	
*P < 0.01			
**P < 0.001			

GP78-0667-3

Figure 39

**Analysis of Variance of Effects of Display Density and Number of Colors upon Search Times (Transformed Data)**  
**(From Cahill, M. and Carter, N.; Reference 67)**

A statistical output from a factorial design is shown in Figure 39. In this example case, there was greater variance in operator performance due to display density than number of colors; also, operator response time was affected by certain combinations of display density and number of colors.

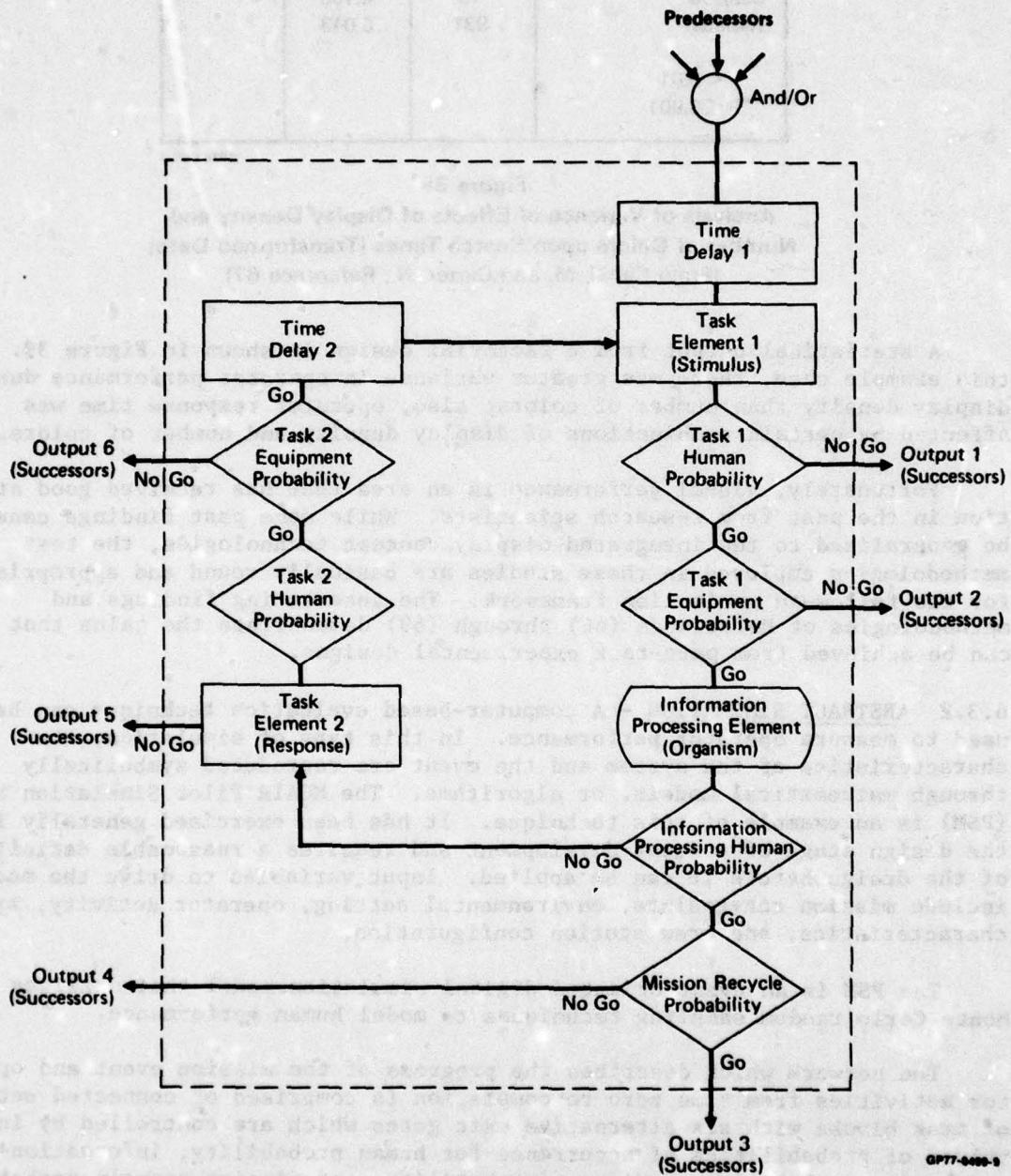
Fortunately, visual performance is an area that has received good attention in the past from research scientists. While some past findings cannot be generalized to the integrated display concept technologies, the test methodologies employed in these studies are basically sound and appropriate for the follow-on evaluation framework. The interesting findings and methodologies of References (66) through (69) demonstrate the gains that can be achieved from part-task experimental designs.

**6.3.2 ABSTRACT SIMULATION** - A computer-based evaluation technique can be used to measure operator performance. In this type of simulation, the characteristics of the system and the event are reproduced symbolically through mathematical models, or algorithms. The MCAIR Pilot Simulation Model (PSM) is an example of this technique. It has been exercised generally in the design stage of concept development and requires a reasonable definition of the design before it can be applied. Input variables to drive the model include mission constraints, environmental setting, operator activity, system characteristics, and crew station configuration.

The PSM is an event-oriented digital simulation model that utilizes Monte Carlo random sampling techniques to model human performance.

The network which describes the progress of the mission event and operator activities from time zero to completion is comprised of connected sets of task blocks with six alternative exit gates which are controlled by inputted values of probabilities of occurrence for human probability, information-processing probability, equipment probability, and mission recycle probability. The task block structure is shown in Figure 40. Figure 41 provides a list of data item requirements for the PSM.

Since the PSM models an event based on what is inputted, the function of the PSM is generally supported by historical data and part-task experimental data which serve as the main data sources. A combination of part-task studies and PSM exercise is considered an excellent evaluation framework for the functional mockup phase.



**Figure 40**  
**Task Block Structure**

Data Item Requirements as a Function of Pilot Simulation Model Routines	Data Item Requirements as a Function of System Under Evaluation
Network Title	Block Title
Number of Replications	Block Number
Number of Blocks in Network	Design Reference
Calendar Switch	Block Repeat Factor
Maximum Block Number	Predecessor Switch
Equipment Probability Switch	Predecessor Block
Number of Personnel	Personnel Identification
Personnel Titles	Block Interrupt
Number of Cockpit Zones	Time Delay
Cockpit Interzone Penalties	Probability Distribution
Numeric Identification of Initial Cockpit Zone	Sensory Function
Cockpit Visual Time Penalty	Human Probability
Number of Equipments	Successor Block
Equipment Title	Environmental Effects
Available Mission Time	System Characteristics
Network Completion Time Distribution	Crew Station Equipment
Number of Calcomp Plots	Equipment Number
	Equipment Probability
	Mission Recycle Probability
	Mission Constraints

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**Figure 41**  
**Pilot Simulation Model (PSM) Input Data**

A distinct advantage of evaluating operator performance by way of an abstract simulation model is that such a model is capable of simulating a complex number of variables without loss of processing efficiency such as would be expected when done by human processors.

#### **6.4 MAN-IN-THE-LOOP SIMULATION**

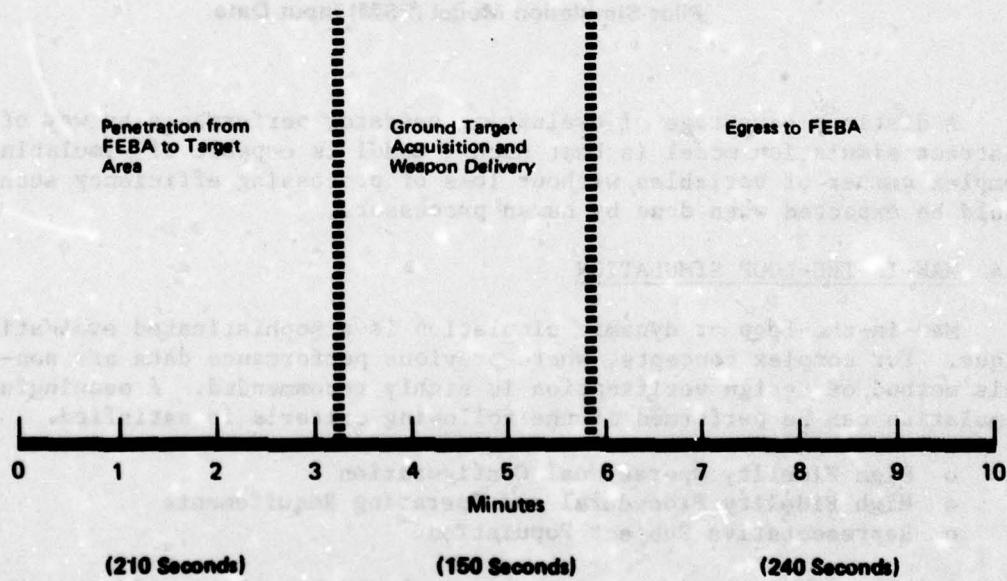
Man-in-the-loop or dynamic simulation is a sophisticated evaluation technique. For complex concepts, where previous performance data are non-existent, this method of design verification is highly recommended. A meaningful simulation can be performed if the following criteria is satisfied.

- o High Fidelity Operational Configuration
- o High Fidelity Procedural and Operating Requirements
- o Representative Subject Population

The more accurate the combat simulation, the higher the confidence that can be placed on the data as predictors of performance.

If the evaluation process has been a continuous one throughout the design process, some reduction in simulation scope may have been achieved. The physical simulation evaluation phase can then be speeded by simulation of selective system performance facets only. In pursuing such an evaluation philosophy for an independent research and development project in pilot information systems, the approach is to concentrate on high workload mission segments, and to evaluate performance of the pilots as they perform primary and secondary tasks in flying through the mission segments. Since the raison d'etre for any offensive-defensive system is its effectiveness in a combat role, it is logical to simulate weapon release performance for various terminal guidance modes such as radar seeker, anti-radiation homing, SAR-aided, EO/IR imaging, and laser tracking. Figure 42 is a generalized mission segment profile that can be detailed to evaluate aircraft control tasks, threat control tasks, target designation tasks, weapons delivery tasks, communications tasks, and navigation tasks.

A major consideration in establishing a study using man-in-the-loop simulation is determining the type of empirical data worthwhile collecting. If design iterations cannot be validly finalized in a functional mockup, performing subjective evaluations using man-in-the-loop simulation is recommended to disclose design problems. Once design iterations have been completed to a degree where changes in the design concept are highly improbable, it may be desirable to collect empirical data on pilot performance to corroborate efficacy of the design from the standpoint of pilot operability.



**Figure 42**  
**Sample Mission Profile**

## **6.5 SUMMARY OF EVALUATION FRAMEWORK**

There are no hard-and-fast rules for selecting one evaluation technique instead of another. Past success is the best criterion. Generally, the stage of the design process will constrain the selection of evaluation approaches. Subjective methods can sometimes be exercised for 100% of the evaluation framework. Other situations would dictate more authoritative figures of merits than judgments. In most cases a combination of all available techniques should be considered for best yield, in terms of the economics of the evaluation method and the gains in certainty that are expected for that method. However, in the final stages of design and prior to release for production, dynamic simulation has generally proved to be the most effective approach in terms of acquiring an overall assessment of the operator interfacing with a system. For this reason, a recommended simulation plan is provided in the succeeding paragraphs.

**6.5.1 RECOMMENDED EVALUATION METHOD** - The evaluation framework heretofore described in Section 6 presented multiple techniques and associated those techniques with potential areas of application during the design process. While it appears likely that some of these will be applied on a small scale, the recommended anchor point for the evaluation is man-in-the-loop simulation. This type of simulation comes closest to an integrated testing approach, i.e., where interdependence of man, hardware, and environment can be studied, and therefore can more fully exploit the potentials of a system than any other evaluation techniques previously described. Manned combat simulation is recognized as the closest complement to flight testing in terms of placing the system in an environment similar to the one in which it will ultimately perform. Design iterations generally occur in a much shorter time frame when simulations are utilized. The need for integrated system testing is necessary in order to achieve a valid pilot workload and effectiveness analysis, which is the primary reason for conducting manned combat simulation.

**6.5.2 WORKLOAD AND EFFECTIVENESS ANALYSIS** - The use of multimode displays for visual presentations of aircrew information in the 1985-1990 fighter/attack crew station is a large and complex task. Considerable gains have been achieved in the study by a systematic investigation of projected mission and weapon requirements, the role of the pilot, and the information he will need to execute his role. This has been followed by a comprehensive review and analysis of visual display system technology, culminating in the selection of three concepts as comparative alternates in the follow-on study. This same level of penetration into pilot workload and effectiveness analysis cannot be achieved within the time frame of this study. An on-the-surface examination of the three technology concepts selected for a follow-on study -- Electroluminescent Devices (ELs), Plasma Display (PLDs), and Cathode Ray Tube Displays (CRTs) -- indicate some similarity in their strong design points. However, in the actual development of display formats, variations will necessarily be introduced to accommodate design differences. Particularly, if these variations affect arrangement, coding and sizing schemes, as well as resolution, brightness and contrast, a valid measure of pilot workload and effectiveness cannot be achieved without assessing the impact of such

variations. A meaningful analysis entails the development of a crew station design complete with controls and displays layout and the generation of applicable multimode display formats for an entire mission. This in-depth analysis can best be accomplished in the evaluation phase of the follow-on study, where planned iterative processes of design and testing will precisely identify the scope of information required for mission accomplishment and the most acceptable formats in terms of low workload.

Typical cockpit layouts that would permit pilot workload analysis in a flight simulator, while also providing an evaluation of various methods of presenting pilot information, are shown in Figures 43 and 44. It is felt that the evaluation technique utilizing dynamic displays under simulated combat mission conditions is far superior to other evaluation techniques that do not present the fully integrated information or task to the flight crews.

## 6.6 SIMULATION PLAN

The purpose of this sub-section is to outline the objectives to be achieved in manned combat simulation and to describe the categories of planning activities that need to be addressed to satisfy the simulation objectives.

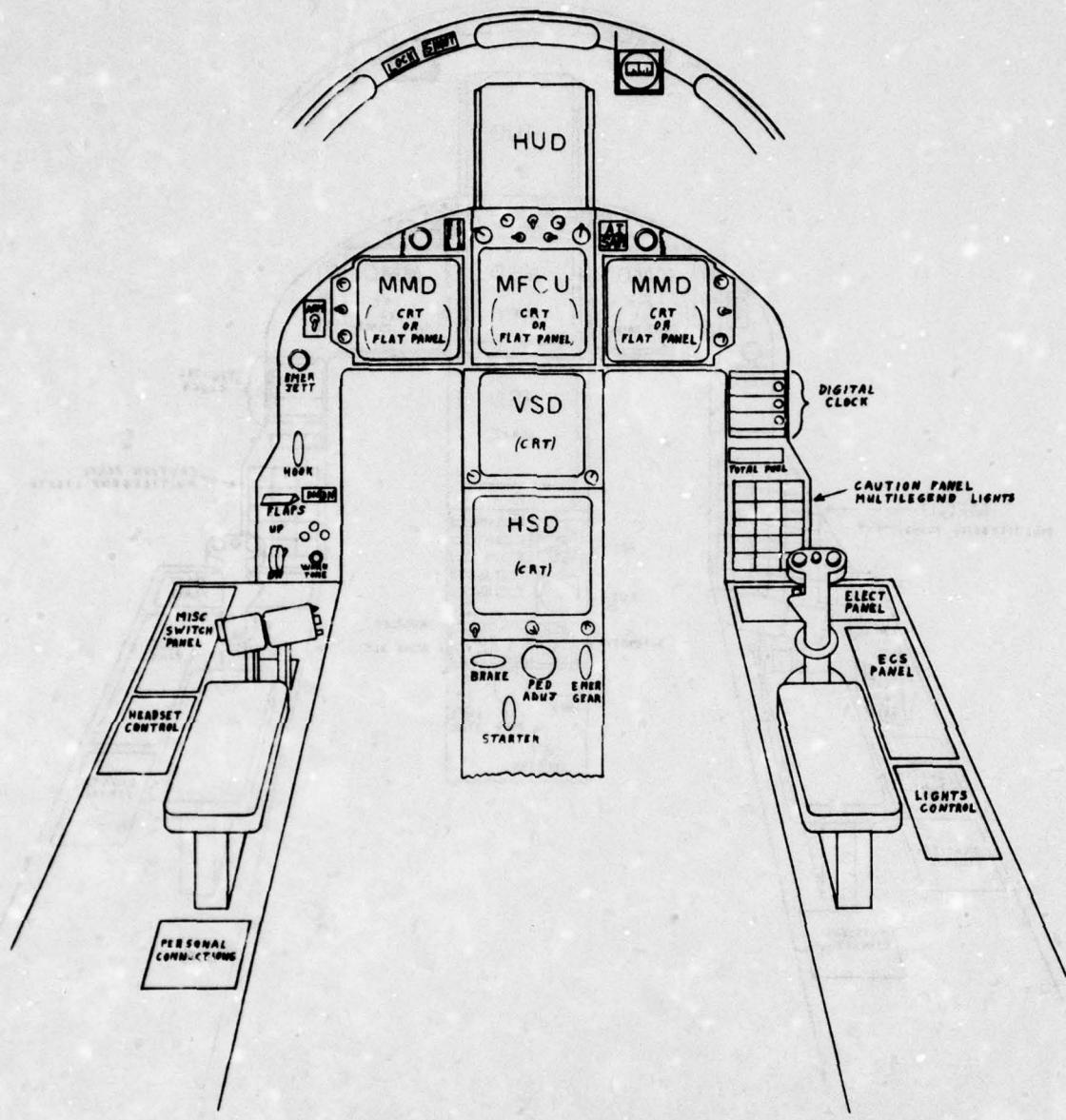
**6.6.1 MANNED COMBAT SIMULATION OBJECTIVES** - Two objectives will be accomplished through the employment of manned simulations as the primary evaluation technique.

o Verify conceptual utility of competing design configurations through appropriate selection of figures of merit.

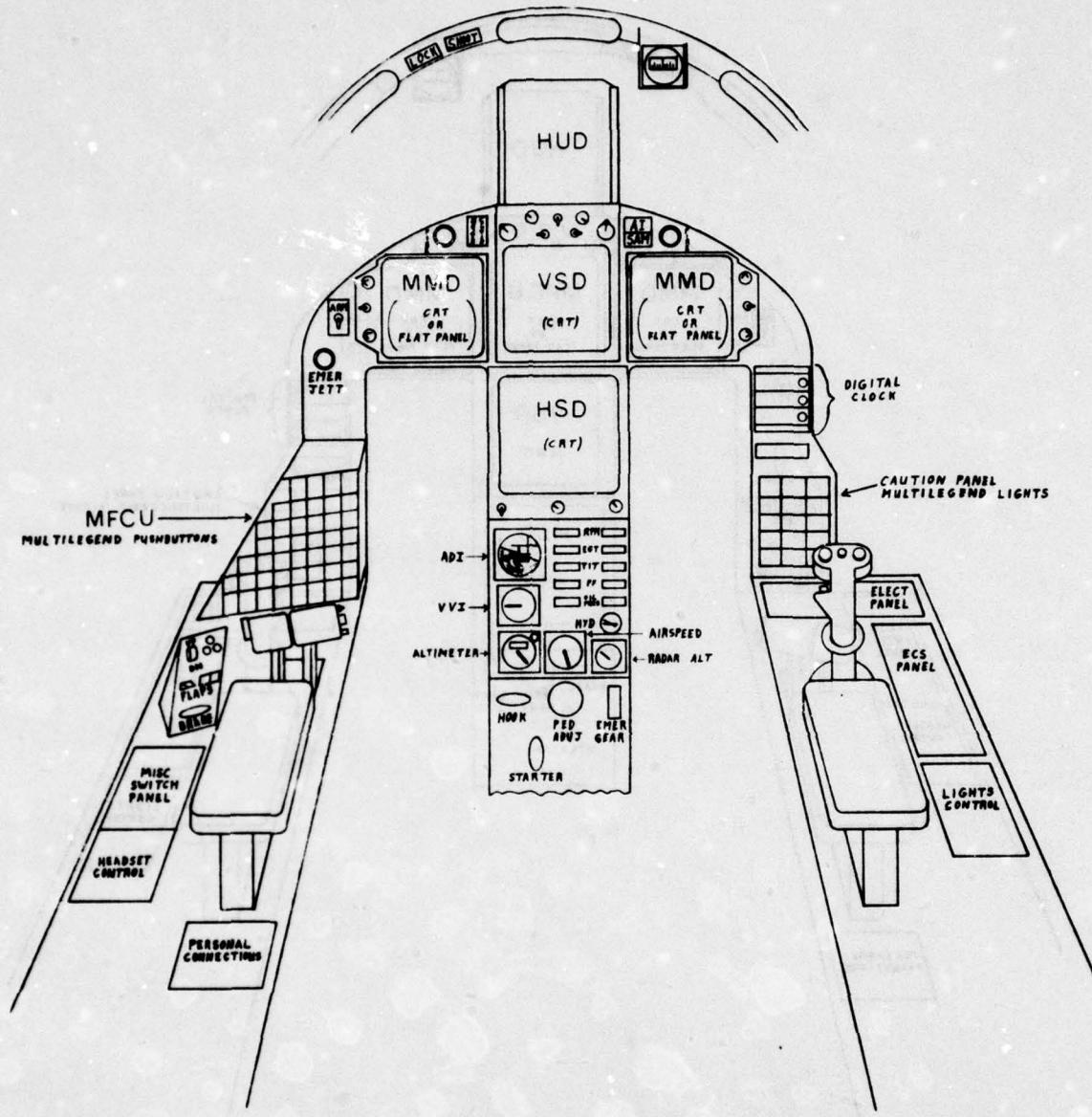
o Provide design guide specifications on operator/display interface criteria.

Both these objectives are explicit in their emphasis on the role of the pilot.

To accomplish such a study, three specific categories of planning activities need to be formulated.



**Figure 43**  
**Candidate Evaluation Control/Display Layout**



**Figure 44**  
**Candidate Evaluation Control/Display Layout**

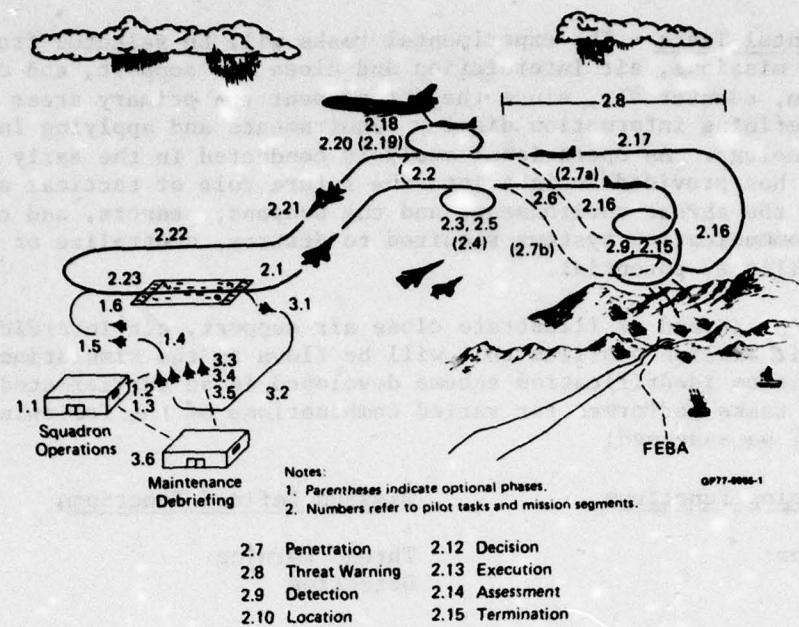
Experimental Tasks - The experimental tasks will be selected from two air-to-ground missions, air interdiction and close air support, and one air-to-air mission, counter air, since these represent the primary areas of emphasis in defining information display requirements and applying integrated concepts technology. An operational analysis conducted in the early months of this study has provided insight into the future role of tactical air power, the nature of the threat environment, and the weapons, sensors, and command, control and communication systems required to destroy, neutralize or delay the enemy's military potential.

Figures 45, 46 and 47 illustrate close air support, air interdiction, and counter air mission profiles that will be flown in the simulation. Using the pilot function identification scheme developed in an earlier study activity, the tasks performed for varied combinations of the following pilot functions will be assessed:

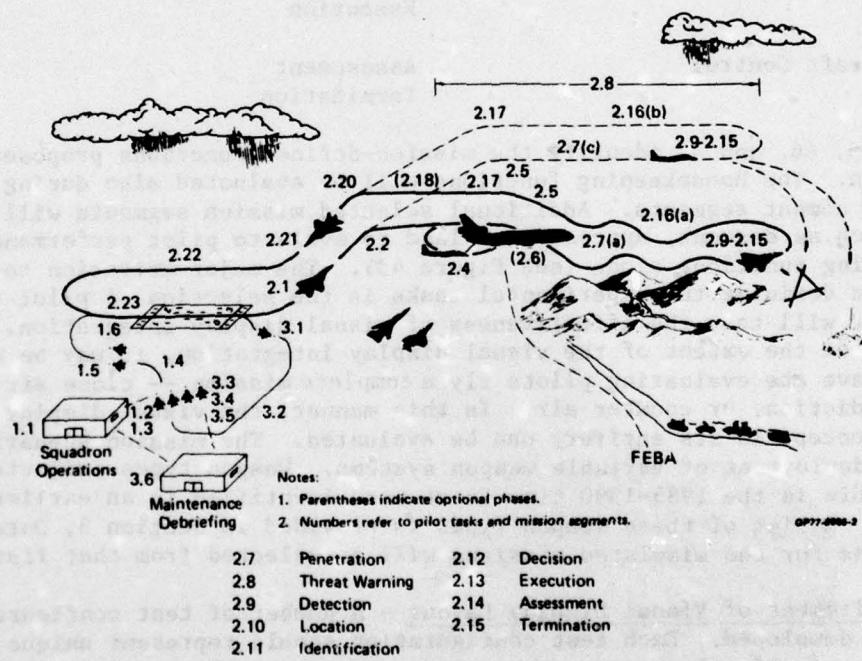
<u>Housekeeping Functions</u>	<u>Mission Defined Functions</u>
Navigation	Threat Warning Detection
Systems Monitoring	Location Identification
Communications	Decision Execution
Aircraft Control	Assessment Termination

Figures 45, 46, and 47 identify the mission-defined functions proposed for evaluation. The housekeeping functions will be evaluated also during the same FEBA combat segments. Additional selected mission segments will be flown, such as descent, approach and land to evaluate pilot performance on housekeeping functions alone (see Figure 45). The major criterion to be applied in defining the experimental tasks is the selection of pilot functions that will test the effectiveness of visual display integration. Depending on the extent of the visual display integration, it may be necessary to have the evaluating pilots fly a complete mission -- close air support, air interdiction, or counter air. In this manner, the visual display integration concept in its entirety can be evaluated. The mission scenarios will consider deployment of variable weapon systems. Weapon types projected to be available in the 1985-1990 time frame were identified in an earlier activity. A list of these weapon types is provided in Section 3, Data Base. The weapons for the simulated missions will be selected from that list.

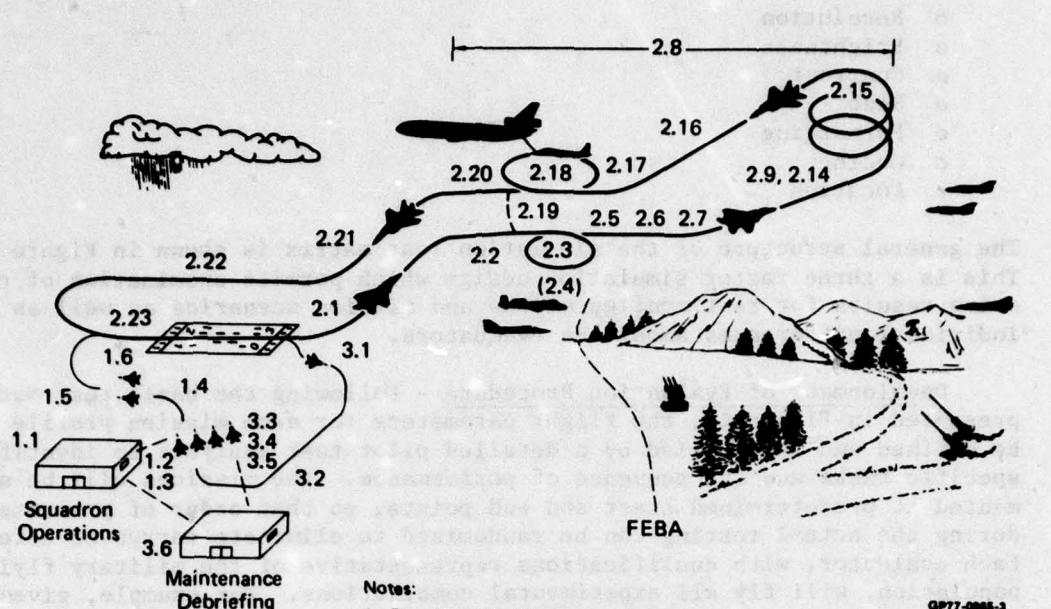
Development of Visual Display Layout - A number of test configurations should be developed. Each test configuration should represent unique differences in a mix of selected options, arrangement, and display formats. The option mixes should consider Electroluminescent Devices (ELs), Plasma Displays (PLDs), and Cathode Ray Tube Displays (CRTs). These were the final display options selected as most worthwhile to pursue for future cockpit



**Figure 45**  
**Close Air Support**



**Figure 46**  
**Air Interdiction**



Notes:

1. Parentheses indicate optional phases.
2. Numbers refer to pilot tasks and mission segments.

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2.1 *	Climb to Level Off	2.13	Execution
2.2	Cruise	2.14	Assessment
2.3	Loiter	2.15	Termination
2.4	Rendezvous and Air-to-Air Refueling (AAR)	2.16 *	Egress
2.5	Coordination	2.17	Cruise
2.6	Mission Rendezvous	2.18	Rendezvous and Air-to-Air Refueling (AAR)
2.7	Penetration	2.19	Reengage
2.8	Threat Warning	2.20	Return to Base
2.9	Detection	2.21	Descent
2.10	Location	2.22	Approach
2.11	Identification	2.23	Landing
2.12	Decision		

\*Additional mission segments will be selected from this group

Figure 47  
Counter Air

applications. Considering the design properties of these options and the pilot information requirements, both of which have been defined in previous study tasks, arrangements in terms of overall cockpit geometry and display formats in terms of pilot information requirements will be evolved. These differences in test configurations identify some of the variables to be evaluated in the simulator. A complete list of test or independent variables to be considered in the simulation will be identified when the visual display layouts have been completed. Past research studies have found that operator performance on visually displayed information is affected by the following display variables. These, therefore, will be high on the list for consideration:

- o Resolution
- o Brightness
- o Contrast
- o Size
- o Formatting
- o Coding
- o Location

The general structure of the simulation test matrix is shown in Figure 48. This is a three factor simulation design which permits examination of comparative results for test configurations and mission scenarios as well as individual differences among the evaluators.

Development of Evaluation Procedure - Following the basic test matrix presented in Figure 48, the flight parameters for each mission profile will be defined and accompanied by a detailed pilot task analysis to identify the specific tasks and the sequence of performance. The missions will be segmented at predetermined start and end points, so that order of presentation during the actual testing can be randomized to eliminate carryover effects. Each evaluator, with qualifications representative of the military flying population, will fly all experimental combinations. For example, given test configuration A<sub>1</sub>, an evaluator will fly all mission segments. He will perform similarly for all test configurations. Prior to formal testing, all evaluators will be processed through a familiarization and learning program on the cockpit test configurations, the pilot's role in overall mission

Mission Profile	Test Configuration A <sub>1</sub>	Test Configuration A <sub>2</sub>	Test Configuration A <sub>3</sub>	Test Configuration A <sub>4</sub>
Mission Scenario B <sub>1</sub> Mission Segment B <sub>11</sub> Mission Segment B <sub>12</sub> Mission Segment B <sub>13</sub> Mission Segment B <sub>1n</sub>				
Mission Scenario B <sub>2</sub> Mission Segment B <sub>21</sub> • • Mission Segment B <sub>2n</sub>			<b>Each Cell Will Contain Evaluation Scores for the Dependent Variables</b>	
Mission Scenario B <sub>3</sub> Mission Segment B <sub>31</sub> • • Mission Segment B <sub>3n</sub>				

Figure 48  
Three-Factor Test Matrix

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performance, and the general operating capabilities of the simulator facilities. Additionally, ample practice in the simulator will be afforded all evaluators as part of the learning process. In the formal experiment, it is planned to have the evaluators perform once under each test condition. The formal test performance will be recorded on magnetic tape for replay. While still in the cockpit, the pilot may request as many replays of his test performance as required to complete his evaluation.

**6.6.2 CREW EVALUATION TECHNIQUES** - Based on the successes of similar techniques in the past, a balanced combination of quantitative and qualitative metrics will be applied.

**Quantitative Metrics** - The simulation system can be configured to provide recording of performance measures. The selection of performance measures is dependent on what are expected to cause variations in pilot performance. The following is a list of performance measures most often used in pilot workload studies:

- o Aircraft Control Tasks:
  1. Altitude error - Deviations from command aircraft altitude
  2. Heading error - Deviations from command aircraft heading
  3. Airspeed error - Deviations from command aircraft airspeed
- o Threat Control Tasks:
  1. Response latency - Time lapse from onset of stimulus to test subject's response
  2. Response accuracy - Number of times a correct response was made or % of correct responses
  3. Omissions - Number of times a response was not made or % of time test subject failed to respond to a test stimulus
- o Target Designation Tasks and Weapons Delivery Tasks:
  1. Target detection - Time lapse between target display and test subject's verbal response
  2. Target acquisition - Time lapse between target acquisition and target designation
  3. Response accuracy - Number of hits for weapons launched  
Number of targets accurately detected
- o Communications Tasks:
  1. Percentage of time pilot speaking
  2. Percentage of time others speaking to pilot
  3. Percentage of time silent

**o Navigation Tasks:**

1. % of correct arrival times at test waypoints
2. Lag and offset ETA expressed in nautical miles

It would appear from the trend of the visual display integration study that selection of performance measures from the first 3 groups would be appropriate.

**Qualitative Metrics** - Rating forms similar to those discussed in Paragraph 6.2 are recommended to complement quantitative metrics. Factors such as pilot acceptability, pilot stress, or pilot fatigue and the like are best evaluated through the use of carefully structured rating forms because empirical assessment is difficult to achieve in the simulator. The rating forms can be designed to provide separate figures of merits for variables of interest as well as an overall figure of merit for a display option.

Free form interviews and questionnaires have the advantage of providing the pilot with an opportunity to express his opinion on design features not covered in the rating forms or the empirical data. It is a promising tool to supplement data acquired in rating forms and manned simulations, and is recommended to round out the simulation plan formulated thus far.

**6.6.3 METHOD OF ANALYZING/SUMMARIZING RESULTS** - Statistical analyses will be accomplished to determine means, standard deviations, and variances. Parametric and nonparametric statistical techniques will be applied to determine concordance of agreement among evaluators and to identify variations in pilot performance attributable solely to test configurations by sorting out the effects of pilot individual difference.

Pursuing further the generalized 3-factor test matrix shown in Figure 48, the decision problem is whether differences among test configuration means are statistically significant. The F-test can be applied to identify such differences. This test is based on a probability distribution, developed out of the concept of sampling from a well-defined universe, using the ratio of two variances computed from the test data to determine whether true differences exist. An extensive explanation of this statistical concept can be found in most statistical textbooks, one of which is cited (Reference (70)). Where more than two test configurations are involved, additional statistical testing needs to be applied to identify which pairs of test configurations are different. Duncan's Multiple Range Test is designed to make such multiple comparisons, using in its mathematical model the standard error of a single mean, degrees of freedom, and the square root of the error mean square of the analysis of variance (Reference (70)). The application of these tests is consistent with previous studies where similar simulation approaches were used.

**o Navigation Tasks:**

1. % of correct arrival times at test waypoints
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Hypothesis testing using the F-Distribution, the Duncan Distribution, or others will identify whether such differences are significant at specified levels of probability. In summary, the statement of findings will describe 1) figures of merit for each mission segment as well as all missions combined, (as a function of test configuration), and 2) whether true differences in performance do exist because of the visual display integration concepts.

Many combinations of statistical methods are open for selection, and the selections will depend on how the actual simulation testing materializes.

**6.6.4 CANDIDATE EVALUATION CONTROL/DISPLAY LAYOUT** - Figures 43 and 44 illustrate typical control/display configurations which would be candidates for simulation testing. These, typically, evolve during the investigative process of developing a design concept. Control and display arrangements, particularly the visual display systems -- HUD, MMD, MFCU, VSD, and HSD -- could conceivably produce different effects upon pilot performance. While special emphasis will be placed on the format structure within each display system, this will not exclude the identification of other variables such as cockpit arrangement. Each test configuration will describe those design attributes which uniquely distinguishes it from other test alternatives, wherein such differences represent potential factors in influencing pilot workload and pilot performance effectiveness.

## 7. SUMMARY OF RESULTS AND CONCLUSIONS

### 7.1 RESULTS

- (a) Mission Profiles - Close Air Support, Air Interdiction and Counter Air mission profiles were generated for the Central European Theater battlefield.
- (b) Current/Projected Weapons - The unclassified current and projected weapons considered available for 1985-1990 attack/fighter missions were determined. Reference (1) was determined as an excellent source of information on unclassified advanced weapons.
- (c) Mission Phases of Flight - The phases of flight were divided into three basic categories: Preflight, In-flight and Post-flight. Each category was expanded to include each segment of a complete combat mission. (See Appendix A.)
- (d) Mission Requirements - The mission requirements were determined for Close Air Support, Air Interdiction and Counter Air missions. (See Appendix B.)
- (e) Air Crew Functions - Crew functions for typical air operations were generated under the two basic categories of Mission and Housekeeping.
- (f) Crew Information Requirements - Crew information requirements were generated in matrix form for Close Air Support, Air Interdiction and Counter Air missions. Each bit of information needed during the Preflight, In-flight and Post-flight phases of the missions was assigned an order of priority for each phase. These three summaries, shown in Section 4, are considered significant results because it is this information that must be displayed in an integrated manner to the 1985-1990 combat crews.
- (g) Display Technologies - The display technologies were surveyed from the standpoint of capability and availability for the 1985-1990 time period. This technology was summarized in matrix form to compare the pertinent characteristics of the most promising display options. The four most promising display options were selected.
- (h) Display Evaluation Framework - Available display evaluation techniques were assessed for their capability in evaluating the selected display integration options in future related work. Manned combat simulation was selected as the most appropriate evaluation technique because of its ability to provide dynamic displays in real time under typical high workload conditions. (See Section 6.) Two suggested crew station layouts were generated for possible use in the follow-on work.

## 7.2 CONCLUSIONS

(a) Selected Display Integration Options - Display options selected on the basis of their capabilities and availability are:

Option 1: Cathode Ray Tube (CRT). The CRT was selected because of the versatility of data that can be displayed with a full video format. It is available now, is considered the standard for comparison, and is expected to retain its preeminence into the late 1980's. Undesirable Characteristics: Volume, weight and power requirement.

Option 2: Plasma Flat Display Panel. The plasma display is the leading contender, on a near term basis, because of the rapid progress made in developing this unit and the fact that it is now commercially available. Undesirable Characteristics: Has difficulty presenting shades of gray, the neon orange color is not always an acceptable color, and it cannot retain contrast in full sunlight.

Option 3: The liquid crystal display (LCD) is also a leading contender (to replace the CRT) for application in a military cockpit due to the development momentum created through military funding of LCD technology. LCDs do require minimal power and retain contrast in a bright ambient. Undesirable Characteristics: Requires supplemental lighting and heating, drive circuitry and wiring interconnect complexities, and (depending on implementation) viewing angle restrictions.

Option 4: Electroluminescence Flat Display Panel with Thin-Film-Transistor Picture Element (EL-TFT). Although speculative and in the early stages of development, EL-TFT is an active display that maintains image brightness and is easily viewable in bright ambient conditions. Their major asset is the efficiency with which their phosphor converts input power to radiated lumens. Undesirable Characteristics: Drive circuitry and wiring interconnect complexities.

(b) Optimum Evaluation Method: Manned Combat Simulations. In order to evaluate the display options such that crew actions and comments can be closely monitored and recorded, the manned combat simulation evaluation technique was selected as the most appropriate display evaluation method. This means, of course, that the following tasks must be accomplished before meaningful results could be obtained:

- (1) a control/display layout selected,
- (2) (typical) aircraft performance selected,
- (3) multimode display formats generated,
- (4) method designed/selected for controlling computer-generated display information,
- (5) simulation evaluation plan generated,
- (6) plan devised for control/assessment of data generated and an iterative design process.

## 8. RECOMMENDATIONS

The following recommendations are made to provide objectives and guidelines for future related visual display integration work. They are specifically directed toward the planning and preparations for conducting an evaluation of the selected display integration options.

- (1) Use Manned Combat Simulation as a primary display evaluation method structured to permit crew evaluation of: (a) display arrangement; (b) display formats; (c) display information content; (d) pilot workload; (e) differences between competing display alternatives; (f) control of computer-generated information; and (g) probability of mission accomplishment and survival.
- (2) Lay out the display arrangement and necessary controls for a fighter cockpit in preparation for an evaluation of display location, readability, information content, display format acceptability, pilot workload, and mission accomplishment. Plan for continued use of CRT (Option 1).
- (3) Develop display formats for each mission segment for all multi-function displays.
- (4) Select an existing high performance aircraft that closely approximates the performance required for fighter mission accomplishment in the 1985-1990 time period. Use data for this aircraft to prepare a simulation program that would permit manned, real-time simulations under typical combat conditions.
- (5) Develop a simulation plan to evaluate selected display options and compare competing alternatives during a typical combat mission. Identify required evaluation and scoring techniques.
- (6) Establish common software and hardware designs of component functions for controls and displays in order to minimize costs.
- (7) In conjunction with display format developments, determine the benefits of color coding for displays, stereo display presentations (i.e., binocular versus monocular), and panoramic information displays.
- (8) Continue development of LCDs, particularly hybrid versions of LCs that employ dichroic or other materials that eliminate the undesirable viewing angle restrictions of many current LCDs.
- (9) Continue search for, and development of, alternative passive display devices/materials (i.e., light modulating rather than emitting) that do not have the viewing angle and temperature range limits of LCDs.
- (10) Develop EL-TFT technology at an accelerated rate where practicable.
- (11) Develop filtering technology (e.g., spectral, polarizing and directional) for contrast improvement.

**APPENDIX A**

**MISSION PROFILES**

**Phases of Flight, Aircrew Functions, and Close Air Support, Air Interdiction, and Counter Air Mission Profiles are summarized herein.**

1. Preflight - All aircrew functions leading up to but not including takeoff.
  - 1.1 Mission Planning
  - 1.2 Preflight
  - 1.3 Start and System Checks
  - 1.4 Taxi
  - 1.5 Arming
  - 1.6 Takeoff
2. In-Flight - All flight activities beginning with takeoff and concluding at the termination of the landing roll.
  - 2.1 Climb to Level Off
  - 2.2 Cruise
  - 2.3 Loiter
  - 2.4 Rendezvous and Air-to-Air Refueling (AAR)
  - 2.5 Coordination
  - 2.6 Mission Rendezvous
  - 2.7 Penetration
  - 2.8 Threat Warning
  - 2.9 Detection
  - 2.10 Location
  - 2.11 Identification
  - 2.12 Decision
  - 2.13 Execution
  - 2.14 Assessment
  - 2.15 Termination
  - 2.16 Egress
  - 2.17 Cruise
  - 2.18 Rendezvous and Air-to-Air Refueling (AAR)
  - 2.19 Reengage
  - 2.20 Return to Base
  - 2.21 Descent
  - 2.22 Approach
  - 2.23 Landing
3. Post-Flight - All mission related activities beginning after the completion of the landing roll and ending when the aircrew is free to perform other duties or pursue personal interests.
  - 3.1 De-arm
  - 3.2 Taxi
  - 3.3 System Checks
  - 3.4 Shutdown
  - 3.5 Post-Flight
  - 3.6 Debrief

**Figure A-1**  
**Mission Requirements: Phases of Flight**

- o Mission\*
  - Detection
  - Location
  - Identification
  - Decision
  - Execution
  - Assessment
  - Formation
  - Threat Warning
- o Housekeeping
  - Navigation
  - Monitor Systems
  - Communications
  - Aircraft Control

\* These functions were defined under mission requirements.

**Figure A-2**  
**Aircrew Functions**

- o Detection
  - Intelligence Report (Preflight)
  - Visual
  - Sensors
- o Location
  - Visual
  - Reference Systems
    - o Correlation
    - o Coordinates
    - o Off Sets
- o Identification
  - Visual
  - Sensors
    - o Dependent (Outside Aid)
    - o Independent (Autonomous)
- o Decision
  - Dependent (Outside Advice)
  - Independent
- o Execution
  - Self-contained
  - Aided
- o Assessment
  - Visual
  - Sensors
- o Formation
  - Control
  - Positioning

**Figure A-3**  
**Aircrew Functions: Missions**

- o Navigation

- Self-contained
- Externally Aides
- Visual

- o Monitor Systems

- Normal Operations
- Malfunctions

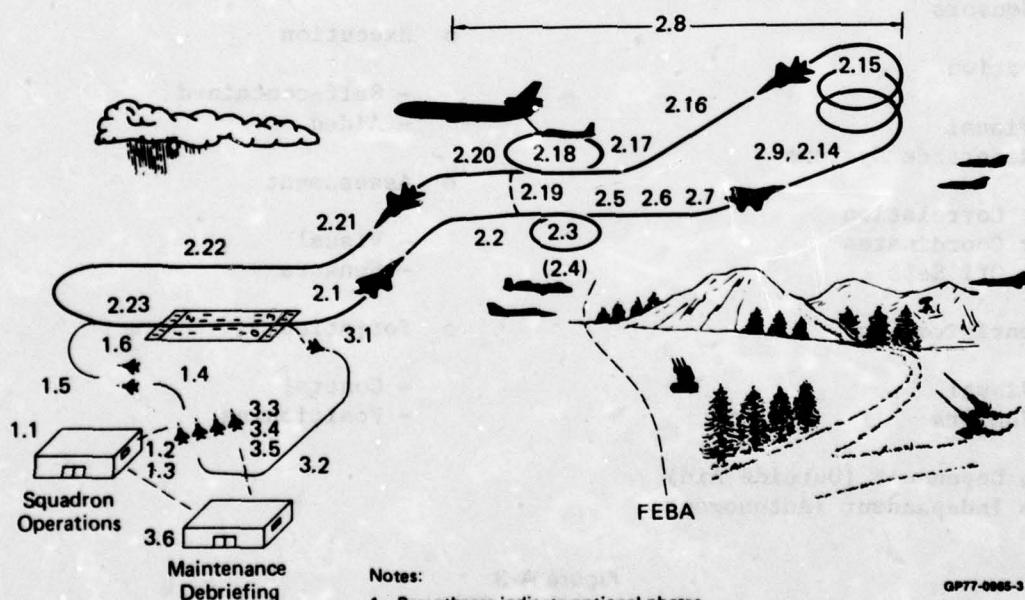
- o Communications

- Transmit
- Receive

- o Aircraft Control

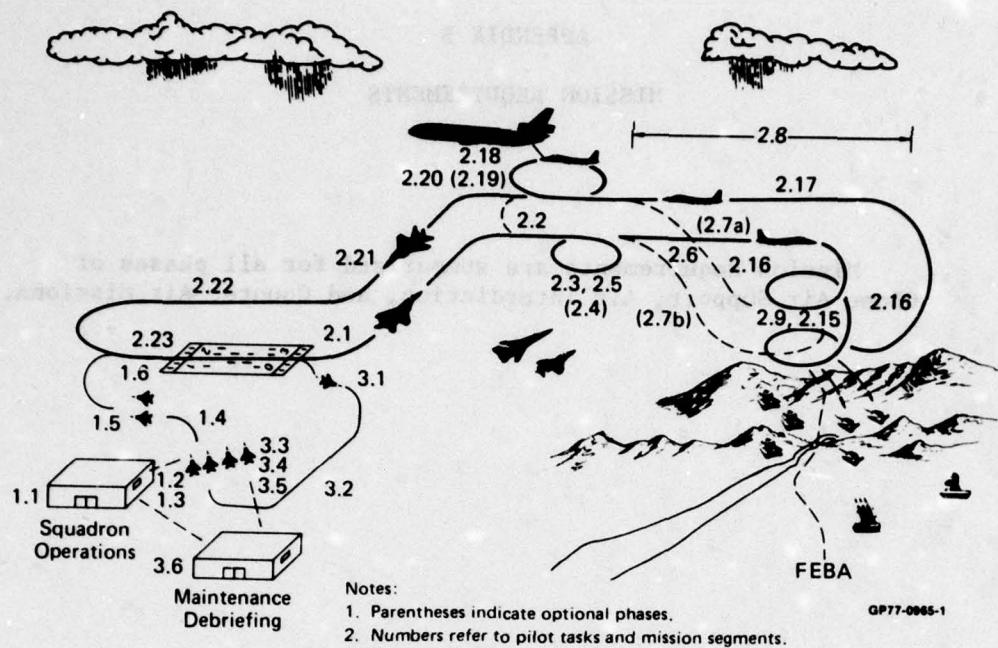
- Climb
- Descents
- Turns
- Straight and Level

**Figure A-4**  
**Aircrew Functions: Housekeeping**

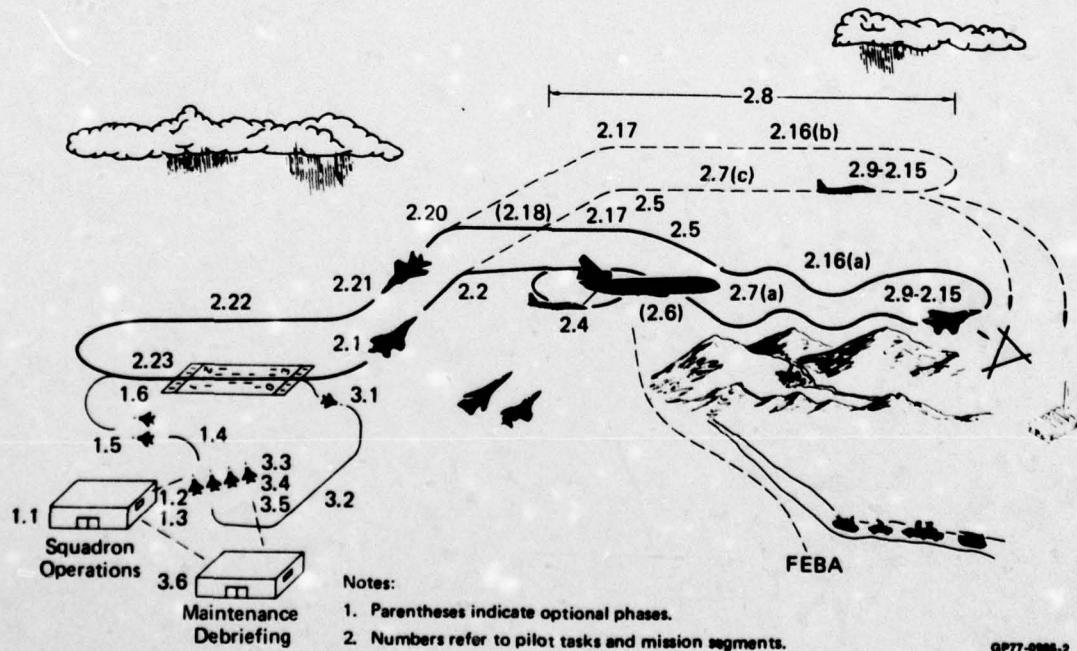


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**Figure A-5**  
**Counter Air**



**Figure A-6**  
**Close Air Support**



**Figure A-7**  
**Air Interdiction**

**APPENDIX B**  
**MISSION REQUIREMENTS**

**Mission Requirements are summarized for all phases of  
Close Air Support, Air Interdiction, and Counter Air Missions.**

1. Preflight - All aircrew functions leading up to but not including takeoff.

- 1.1 Mission Planning
- 1.2 Preflight
- 1.3 Start and System Checks
- 1.4 Taxi
- 1.5 Arming
- 1.6 Takeoff

2. In-Flight - All flight activities beginning with takeoff and concluding at the termination of the landing roll.

- 2.1 Climb to Level Off
- 2.2 Cruise
- 2.3 Loiter
- 2.4 Rendezvous and Air-to-Air Refueling (AAR)
- 2.5 Coordination
- 2.6 Mission Rendezvous
- 2.7 Penetration
- 2.8 Threat Warning
- 2.9 Detection
- 2.10 Location
- 2.11 Identification
- 2.12 Decision
- 2.13 Execution
- 2.14 Assessment
- 2.15 Termination
- 2.16 Egress
- 2.17 Cruise
- 2.18 Rendezvous and Air-to-Air Refueling (AAR)
- 2.19 Reengage
- 2.20 Return to Base
- 2.21 Descent
- 2.22 Approach
- 2.23 Landing

3. Post-Flight - All mission-related activities beginning after the completion of the landing roll and ending when the aircrew is free to perform other duties or pursue personal interests.

- 3.1 De-arm
- 3.2 Taxi
- 3.3 System Checks
- 3.4 Shutdown
- 3.5 Post-Flight
- 3.6 Debrief

**Figure B-1**  
**Mission Requirements: Phases of Flight**

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
1. Preflight	<p>1.1 Mission Planning</p> <p>1.1 All tasks necessary for safe and effective conduct of the mission. This includes at a minimum:</p> <ul style="list-style-type: none"> <li>(a) Briefings: weather, intelligence, flight, rules of engagement, target, and weapon deliveries.</li> <li>(b) Computations: time, distance, headings, fuel, and ballistics.</li> <li>(c) Maps</li> <li>(d) Enroute Procedures: formation, navigation, communications.</li> <li>(e) Air refueling procedures and call signs.</li> <li>(f) Alternate missions</li> </ul> <p>(See Note 1)</p>	<p>1.1 Same as Close Air Support (See Note 2)</p>	<p>1.1 Same as Close Air Support (See Note 3)</p>

NOTES:

- (1) Close Air Support missions emphasize quick response and receive the highest possible priority when friendly forces are actively engaged and in desperate need of all available resources to counter the enemy. Therefore, if a mission is scrambled from an alert status or diverted from another mission, there may be little or no time available for mission planning. In these cases the aircrew must rely on experience, on board systems, and in-flight communications to provide him the information needed to complete the mission.
- (2) Because Air Interdiction missions are generally conducted against larger less mobile targets, (See Figure A7) there is frequently more time available for detailed flight planning. With the exception of the shallow interdiction mobile targets, a target's location and description are usually very accurately known. In general, fewer unexpected decisions are necessary than on a Close Air Support mission.

**Figure B-2**  
**Mission Requirements**

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
NOTES: (Continued) (3) Although Counter Air missions are very demanding, requiring polished pilot skills, they generally require less detailed mission planning than the air-to-ground missions, but more in-flight decisions.			

**Figure B-2 (Continued)**  
**Mission Requirements**

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
1.2 Preflight	<p>(a) Personal Equipment: all tasks associated with the inspection and donning of personal flight gear, i.e., g-suits, parachutes, helmets, etc</p> <p>(b) Aircraft: assure aircraft is in safe physical condition for flight and that it is equipped properly for the proposed mission. Check items, such as fuel or hydraulic leaks, weapon configurations, reservoirs, tires, panels, etc.</p> <p>(c) The aircrew is also responsible for checking the AFTO 781 to assure the aircraft has been properly serviced and released for flight by maintenance. Open discrepancies (items not repaired) and their affect on the proposed mission are evaluated at this time. (See Note 4)</p>	<p>Same as CAS. (See Note 4)</p>	<p>Same as CAS. (See Note 4)</p>

NOTE:

- (4) Most preflight tasks are performed in advance of an aircraft going on alert. Alert status requires specified aircraft and aircrews and, therefore, reduces the resources available for other missions or duties.

**Figure B-2 (Continued)**  
**Mission Requirements**

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
1.3 Start and System Checks	1.3 Check normal system operations. Verify equipment operation applicable to mission. Make go/no go decision depending on equipment status.	1.3 Same as CAS.	1.3 Same as CAS
1.4 Taxi	<p>1.4</p> <p>(a) Receive clearance</p> <p>(b) Taxi aircraft from parking area to arming area exercising caution to avoid other aircraft and maintenance vehicles and equipment.</p> <p>(c) Aircraft must be taxied in appropriate formation position regardless of position on ramp so that arming and takeoff can proceed as planned.</p> <p>(See Note 5)</p>	<p>1.4 Same as CAS (See Note 5)</p>	<p>1.4 Same as CAS (See Note 5)</p>

NOTE:

(5) Ramp congestion, damage, night operations, a strange airfield with unfamiliar procedures, or other unusual circumstance can significantly confuse taxi operations. The results can vary from a delayed mission to damaged or even destroyed aircraft.

**Figure B-2 (Continued)**  
**Mission Requirements**

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
1.5 Arming	1.5 Aircraft weapons and munitions are armed and mechanically unsafed by ground crews. The aircrew is required to maintain his hands off of all switches and controls and, if possible, in a position visible to the ground crew.  (See Note 6)	1.5 Same as CAS	1.5 Same as CAS
1.6 Takeoff	<p>1.6 Same as CAS (See Note 7)</p> <p>(a) Receive clearance</p> <p>(b) Lineup checks (systems and configuration checks).</p> <p>(c) Takeoff Roll - One of most critical phases of flight because of the criticality of major system malfunction, such as engine failure, fires, etc.</p> <p>(d) With live munitions on board, this phase of flight is further complicated because of different handling characteristics such as rotation and lift off speeds, and the slower acceleration of the aircraft.</p>	<p>1.6 Same as CAS except: (d) does not normally apply, because the munitions generally weigh much less and therefore have a much less affect on the aircraft's performance.</p>	<p>1.6 Same as CAS except: (d) does not normally apply, because the munitions generally weigh much less and therefore have a much less affect on the aircraft's performance.</p>

NOTES:

- (6) Arming is generally conducted in a clear area as close to the end of the runway as possible. No additional maintenance can be performed on the aircraft unless it is once again safed. Although arming is a relatively simple procedure, it ranks very high in importance. If done improperly, it can result in an ineffective mission or damage or loss of the aircraft and aircrew. In some modern aircraft systems, because of the aircraft's general configuration, it is impossible for the aircrew to confirm that the ground crew has properly performed their tasks. There are no cockpit indications to indicate that "pins" have been pulled or that a weapon, such as a gun, is armed.

**Figure B-2 (Continued)**  
**Mission Requirements**

PHASE	CLOSE AIR SUPPORT	AIR INTERFUSION	COUNTER AIR
NOTES: (Continued)	(7) If nuclear weapons are carried, then takeoff, abort and jettison procedures may change. Nuclear weapons will not be jettisoned from a military aircraft even with an emergency.		

**Figure B-2 (Continued)**  
**Mission Requirements**

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2. In-Flight 2.1 Climb to Level Off	<p>2.1</p> <p>(a) Monitor systems and perform additional system checks.</p> <p>(b) Monitor Formation.</p> <p>Formation considerations are required throughout the remainder of the flight and vary depending on phase, weather, and enemy action. (The requirements related to leading a formation are so varied that it is impossible to briefly address them. They are, however, a primary consideration in multi-aircraft missions and will receive appropriate emphasis in follow-on studies.)</p> <p>(c) Follow clearance instructions (See Note 8)</p>	<p>2.1 Same as CAS except: formation considerations may not always be required. Some air interdictions are conducted single ship or independent attacks and are altogether dependent on their individual aircraft systems.</p>	<p>2.1 Same as CAS</p>

NOTE:

- (8) Formation procedures for a specific aircraft are very clearly defined and allow for little deviation. To become a highly qualified flight leader, takes years of experience and a demonstrated ability to use good judgement.

**Figure B-2 (Continued)**  
**Mission Requirements**

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.2 Cruise	<p>2.2</p> <ul style="list-style-type: none"> <li>(a) Monitor systems</li> <li>(b) Review mission</li> <li>(c) Follow clearance instructions</li> </ul>	<p>2.2 Same as CAS. In addition:</p> <ul style="list-style-type: none"> <li>(a) Time spent in cruise conditions may be much greater than CAS or counter air.</li> <li>(b) Timing considerations are more critical than CAS or counter air.</li> </ul>	2.2 Same as CAS

**Figure B-2 (Continued)**  
**Mission Requirements**

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.3 Loiter	2.3 Remain in a specified location awaiting further enemy activity or until additional instructions are received.	2.3 Not normally required.	2.3 Same as CAS
2.4 Rendezvous and Air-to-Air Refueling (AAR)	<p>(2.4 Optional. Otherwise same as Air Interdiction. AAR would, normally, only be required if there were extensive delays getting onto a target or if the airbase is at a greater distance from the target area than generally desired.) (See Note 9)</p> <p>(2.4 Optional. Otherwise same as Air Interdiction. Would be used to extend loiter time awaiting engagements.)</p> <p>(a) Rendezvous consists of joining mission aircraft with the tanker face. This phase is not normally pre-briefed between tanker and mission aircrews and relies heavily on standard procedures and the ability to arrive at a specific point, time, altitude, and air-speed.</p> <p>(b) This phase must be conducted in a "safe" area or the tankers must be provided cover against enemy aircraft.</p> <p>(See Note 10)</p>	<p>(2.4 Optional. Otherwise same as Air Interdiction. Would be used to extend loiter time awaiting engagements.)</p> <p>(a) Rendezvous consists of joining mission aircraft with the tanker face. This phase is not normally pre-briefed between tanker and mission aircrews and relies heavily on standard procedures and the ability to arrive at a specific point, time, altitude, and air-speed.</p> <p>(b) This phase must be conducted in a "safe" area or the tankers must be provided cover against enemy aircraft.</p> <p>(See Note 10)</p>	<p>(2.4 Optional. Otherwise same as Air Interdiction. Would be used to extend loiter time awaiting engagements.)</p> <p>(a) Rendezvous consists of joining mission aircraft with the tanker face. This phase is not normally pre-briefed between tanker and mission aircrews and relies heavily on standard procedures and the ability to arrive at a specific point, time, altitude, and air-speed.</p> <p>(b) This phase must be conducted in a "safe" area or the tankers must be provided cover against enemy aircraft.</p> <p>(See Note 10)</p>

NOTES:

- (9) Both loiter and AAR are ways of extending mission time. This has several advantages, such as decreasing the response time necessary to get friendly air power onto a target or increasing the chance of an engagement. As long as adequate weapons are available on board an aircraft, it is more advantageous to keep it airborne awaiting conflict. Other limits to be considered are crew fatigue, aircrew exposure to risk, and support forces, such as the tankers.
- (10) AAR can also be conducted under radar vectors from ground radar control facilities. This is a quicker more efficient method which reduces aircrew tasking, however, it relies heavily on radar and communications and is therefore subject to jamming or deception.

**Figure B-2 (Continued)**  
**Mission Requirements**

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.5 Coordination	<p>2.5</p> <p>(a) Aircrew receives general instructions and sufficient details to contact a specific ground or airborne forward air controller (FAC).</p> <p>(b) FAC provides details of target, such as type, number, specific target location, enemy defenses, and restrictions such as attack headings and friendly troop positions. He may also mark the target with smoke rockets.</p> <p>(c) The FAC, in many cases, will act as the controller and give positive clearance to release ordnance. This is particularly true in cases where enemy and friendly forces are in very close contact to each other.</p>	<p>2.5</p> <p>(a) Receive final clearance for primary mission or a change to a secondary mission. Recent information will be added, such as a weather update or the position of enemy fighters, if available.</p> <p>(b) Authenticate message if a change in mission. This may also be required to confirm go-ahead on mission.</p> <p>(c) Additional information may be relayed in the "blind" such as fighter escort call signs, tankers, and SAM warnings.</p> <p>(See Note 12)</p>	<p>2.5</p> <p>(a) Fighters will be directed to areas of suspected enemy activity.</p> <p>(b) Warnings will be transmitted when enemy aircraft are observed maneuvering for an attack on friendly fighters.</p> <p>(c) SAM warnings will be issued when possible.</p>

NOTES:

- (11) The Tactical Air Control System (TACS) is the coordinating system that is used with both preplanned and immediate CAS operations. This system provides hardware, command and control, and an approved interface with Army commands for the effective use of CAS and some shallow interdiction missions. (See appropriate TAC, AF, and Army regulations.)

**Figure B-2 (Continued)**  
**Mission Requirements**

PHASE	CLOSE AIR SUPPORT	A2O INTERCEPTION	COUNTER AIR
NOTES: (Continued)	(12) Since many of the aircrews and aircraft dedicated to this mission are nuclear capable, the aircrews and maintenance teams must also be knowledgeable of the applicable directives and safety requirements. These directives are quite thorough and allow no room for deviation or error. In general, they further complicate the aircrews training and subsequent crew information needs, especially when qualification and currency is required simultaneously in nuclear and conventional munitions.		

**Figure B-2 (Continued)**  
**Mission Requirements**

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.6 Mission Rendezvous	<p>2.6 Join up at a specified position and time or through radar vectors with other elements of the strike force such as fighter cover and/or screening forces such as ECM or Chaff dispensing aircraft. Easy detection and identification is important during this phase in order to avoid compromising errors. Common radio frequencies facilitate this type of join up.</p> <p>(See Note 13)</p>	<p>2.6 (Optional: Not normally required on deep interdiction missions. May be required on shallow interdiction missions, in which case the same as portions of the close air support requirements would be necessary.)</p>	<p>2.6 Optional:</p> <p>(a) On many missions a counter air strike force operates independently. In this case, positive target identification is required prior to attack.</p> <p>(b) Joinings with other elements in the strike force is required. Usually the counter air forces would be tasked to provide fighter cover. This join up could be with elements of either the CAS or Air Interdiction missions and can require very different tactics to maintain formation integrity with the strike force and provide effective cover.</p> <p>(See Note 13)</p>

NOTE:  
(13)

Elements joining together in a common strike force may be from different units or different bases. They may not have formally briefed together and therefore rely on instructions handed down through the chain of command. This can make initial join up very interesting, since none of the elements may know exactly what to anticipate. It is possible, but very undesirable, that a join up can be attempted with unfriendly forces. This means recognition is necessary as early as possible to avoid what could otherwise prove a disastrous air battle. Therefore, rendezvous relies heavily on radar, UHF communications, and pre-briefed signals or codes.

**Figure B-2 (Continued)**  
**Mission Requirements**

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.7 Penetration	<p>2.7</p> <p>(a) Medium: This tactic will be used primarily when enemy forces have no ground defenses or only light arms fire. Also used when enemy air is not a threat or fighter cover is provided. CAS aircraft will fly into the target area and descend to combat altitudes or join with the FAC for additional instructions. Fighter cover would remain high.</p> <p>(b) Low: This tactic is employed when the CAS aircraft are operating in a heavily defended area. The formation would be split or staggered in an "in trail" formation and penetrate at very low altitudes using the terrain to mask their penetration. In the vicinity of the target area the aircraft would "pop up" to deliver their weapons and when the ordnance is expended, egress at low altitudes. This profile is considerably more demanding on the crew, since the low level route must be flown precisely by all members of the formation. The target area must be somewhat familiar or easily distinguished, since there is little time for search and identification.</p>	<p>2.7</p> <p>(a) Low: For deep interdiction this is a preferred method. It uses terrain masking to conceal the penetrator until in the target area. This takes advantage of surprise and reduces the exposure to enemy defenses. This mission requires sophisticated aircraft systems for night or adverse weather conditions, such as terrain following radar (TFR) and very accurate navigation systems.</p> <p>(b) Medium: Not shown in Figure A7 is the possibility of a medium altitude penetration. This is considered an unattractive option for future systems because it allows almost every enemy system an opportunity to detect and fire at the aircraft and medium altitudes do not offer any natural protection. However, advances in ECM and other self-defense mechanisms could make it an attractive option.</p> <p>(c) High: This option allows the aircraft to fly above most of the enemy threats and utilizes relatively high speeds to reduce exposure to the remaining few enemy aircraft capable of sustained high altitude operation. Requires new uses of advanced technology.</p>	<p>2.7 Optional: It is unlikely that friendly counter air sorties would, by themselves, penetrate heavily defended areas to patrol for enemy fighters. They may go on escort missions with shallow interdiction strike forces, but usually the make up of these strikes reduce enemy defenses.)</p>

**Figure B-2 (Concluded)**  
**Mission Requirements**

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.8 Threat Warning	<p>2.8</p> <p>(a) Aircraft must know well in advance of actual enemy air attacks. This is because CAS are usually slower and less capable aircraft especially when heavily loaded with ordnance. This information may come from onboard systems or be relayed from ground radar.</p> <p>(b) The location of ground based enemy systems must be known preferably in advance of a mission. CAS aircraft are very vulnerable to such systems, particularly SAM's and heavy AAA, and therefore should altogether avoid or at least limit their exposure time to such defenses.</p> <p>(c) Inherent in a detection system should be the required action to defeat the detected enemy threat. This can range from maneuvering, to the use of chaff, flares, or ECM systems.</p>	<p>2.8 Basically the same requirements as CAS aircraft. In general, air interdiction aircraft are sometimes more capable and therefore can more easily evade enemy defensive systems. However, since they operate at a greater distance from friendly forces, they can not always make use of friendly ground based alerts, or cautions.</p> <p>(a) SAM and enemy fighters are the two biggest threats to counter air aircraft. Since new counter air aircraft are extremely capable, they can either avoid or defeat enemy SAM or fighters provided they are detected ahead of time and their position is known.</p> <p>(b) Some countermeasures are necessary to provide additional protection and relieve the aircrews self-defense tasking.</p>	<p>2.8</p> <p>(a) SAM and enemy fighters are the two biggest threats to counter air aircraft. Since new counter air aircraft are extremely capable, they can either avoid or defeat enemy SAM or fighters provided they are detected ahead of time and their position is known.</p>

Figure B-2 (Continued)  
Mission Requirements

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.9 Detection (Determination that a potential target may exist. Sources may vary. Initiates the completion of the remaining mission functions.)	<p>2.9</p> <p>(a) First phase of actual combat. This task may have been performed prior to the mission characteristics are used in the mission planning. The briefed target characteristics are also used for the final determination of the actual target on the mission. This is frequently done using target or route folders that graphically depict the target.</p> <p>(b) This task can be accomplished by a ground based or airborne FAC. The FAC will then advise the mission aircraft of the targets.</p> <p>(c) In designated free fire zones, the flight leader may detect targets of opportunity without specific "detailed coordination" with the ground forces.</p> <p>(d) CAS is concerned only with detecting enemy ground targets.</p>	<p>2.9 This task, because of the general target types, is usually completed well in advance of the mission. The target type and characteristics are used in the mission planning.</p> <p>The briefed target characteristics are also used for the final determination of the actual target on the mission. This is frequently done using target or route folders that graphically depict the target.</p> <p>(d) Air interdiction is concerned only with enemy ground targets.</p>	<p>2.9 Since enemy aircraft are the only targets considered, information related to their position must be very near real time. Therefore there is a much greater emphasis on the mission aircraft having an on-board ability to detect enemy aircraft while the aircraft is in flight. Detailed flight planning based on an enemy being at a certain place and time is of little value.</p>

**Figure B-2 (Continued)**  
**Mission Requirements**

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.10 Location (Potential target placed into or positioned within a designated reference system. The purpose is to locate the target with sufficient accuracy to support the remaining functions, i.e., identification, decision, execution, and assessment.)	<p>2.10 (a) Location must be very accurately known, particularly in reference to friendly forces. This task can be prepared for before flight, but usually must be completed in flight, since targets may have moved or can be camouflaged.</p> <p>(b) The aircrew must make final determination of the targets location. (See Note 14)</p>	<p>2.10 Location must be precisely known relative to the aircraft systems. Usually the tasking of this mission is so demanding that any system that does not direct the on-board sensors or weapons to the close proximity of the target, is not adequate.</p> <p>(See Note 15)</p>	<p>2.10 Location for counter air targets is usually a relative position. This information must be known in order to use air-to-air tactics or weapons. Pre-mission planning is usually of limited value. In-flight updates are very beneficial in giving the counter air forces a overview of the air battle.</p>

NOTES:

- (14) Future weapon concepts present options that may no longer require the CAS aircrew to make the final determination of target and target location.
- (15) The value of detailed mission planning is reduced because air targets can vary their location over a relatively broad spectrum of altitudes and locations with ease. Therefore, well trained and disciplined crews are required that have the experience to take advantage of a very flexible battle arena.

**Figure B-2 (Continued)**  
**Mission Requirements**

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.11 Identification	<p>2.11 Positive identification is the single most important task in CAS. The target must be clearly identified as an enemy. If this cannot be done, the attack can not continue.</p> <p>Sufficient detail visual confirmation is frequently the only method to accomplish this task.</p> <p>(See Note 16)</p> <p>This may require information from several sources or simple visual identification.)</p>	<p>2.11 Identification is important to mission success but less than that required for CAS. Since air interdiction attacks are usually conducted well behind enemy lines and are, therefore, less likely to affect friendly forces if an error is made.</p> <p>(See Note 17)</p>	<p>2.11 Identification in an air battle is extremely important, particularly in theatres mixed with different formations and different types of aircraft. Therefore, "beyond visual range" targets require another method to confirm them as either a friend or foe, such as IFF, operating characteristics, or radar signature.</p> <p>Close in combat is ideally suited for visual identification. Beyond visual range combat relies on other methods and is further restricted by rules of engagement.</p>
NOTES:	<p>(16) In an all weather CAS scenario, it is important to identify a observed object as not only a tank, but also whether it is a friendly or enemy tank. The difference, of course, is substantial and further complicates an already difficult mission.</p> <p>(17) This is not altogether true since the "rules of engagement" (ROE) may still require positive target identification comparable to CAS. The goal in this regard is to either limit nonmilitary collateral damage or avoid acts that might precipitate other countries alignment or aid to the enemy.</p>		

**Figure B-2 (Continued)**  
**Mission Requirements**

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.12 Decision (Potential targets and resources are assessed and a course of action is determined. This function requires the integration of many other functions, capabilities, and resources.)	<p>2.12 The final decision regarding actual weapons release is made by the aircrew. He makes this decision based on the information received up to and including the time of release. (In real combat there is very real "perceived" pressure to release the ordnance and get out of the target area.) Frequently the action of aircrews in combat is not always initially predictable. An aircrews reliability increases as he becomes "combat seasoned." In all cases the aircraft commander makes the final decision as to the weapon release and the target selected.</p> <p>(See Note 18)</p>	<p>2.12 Same as CAS. Additionally, because the attack may be conducted against targets not visually identified, the pilot's feelings may be more academic and less involved in the dynamics of seeing an enemy and subsequently attacking.</p> <p>(See Note 18)</p>	<p>2.12</p> <ul style="list-style-type: none"> <li>(a) Same as CAS except: Only air targets are considered. In close combat the decision is only "when to fire" as there is usually little doubt about the targets identification.</li> <li>(b) Beyond visual range targets must be identified by other methods and therefore the confidence of any decision is not as great or as quick as if visually confirmed. Positive identification, as early as possible, is necessary for a timely decision.</li> </ul> <p>(See Note 18)</p>

NOTE:  
(18) The decision to release weapons in combat is not always easy to explain. Training, ROE's, previous experience the way an aircrew feels, and many other factors can go into a split second decision.

**Figure B-2 (Continued)**  
**Mission Requirements**

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.13 Execution (This is the function in which the chosen course of action is implemented. This action may be either a defensive or offensive action.)	2.13 Execution requires that the final consent be given to the chosen course of action. (In advanced weapons, the weapon may require additional guidance until final impact.) Frequently the actual time of release is computed automatically and, provided there is consent, the weapon is released. Execution presumes all other arming functions are completed.	2.13 Same as CAS	2.15 Same as CAS

**Figure B-2 (Continued)**  
**Mission Requirements**

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.14 Assessment (This is the function in which the impact of aerospace operations upon enemy forces and capabilities is appraised. The purpose of this function is to provide an objective evaluation of the degree to which current operations achieve assigned objectives.)	2.14 This task requires objective evaluation of the damage done. The aircrew can contribute to the success of this task, however, sometimes conditions reduces the aircrew's ability to observe or assess damage in the target area, such as smoke and dust, enemy activities, weather, etc. Therefore, this task is frequently better performed by the FAC or a data reconnaissance flight. The importance of assessment is usually directly proportional to the priority of the target. Frequently the aircrew has no way to record his assessment of damage or events and must rely on his memory to accomplish debriefing. Accuracy is the key element. (See Note 19)	2.14 Same as CAS, except the FAC may not always be in a position to realistically assess the mission success.	2.14 In close combat, assessment can vary from immediately obvious to unobserved. The task is further complicated since later reconnaissance flights are of little value. Therefore, aircrews observing the actual aircraft destruction is one of the best and easiest methods. Beyond visual range successes must be determined by other methods or subsequent evaluation.

NOTE:  
(19) Each combat mission has the potential to acquire a great deal of useful intelligence. This is frequently limited to the ability of the aircrew to observe and take notes. Unless the aircraft is specially equipped, there are few aircrew aids to help with this secondary task.

Figure B-2 (Continued)  
Mission Requirements

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.15 Termination	<p>2.15 At some point the aircrew must make the decision to terminate the engagement. This decision is made based on the following variables.</p> <ul style="list-style-type: none"> <li>(a) Target destroyed</li> <li>(b) Fuel status</li> <li>(c) Ordnance remaining</li> <li>(d) Other circumstances such as a mission recall, heavy enemy defenses, damaged aircraft, deteriorating weather, etc.</li> </ul> <p>On air-to-ground missions, it is easy for the aircraft to separate from the ground targets at will.</p>	<p>2.15 Same as CAS except:</p> <ul style="list-style-type: none"> <li>(a) Deep strike air interdiction missions terminate at weapons delivery. Reattacks are not usually planned, however, more than one target can be attacked.</li> <li>(b) Shallow interdiction missions may allow for multiple attacks on the same target, in which case the same criteria as CAS will apply.</li> </ul>	<p>2.15 Same as CAS. An additional consideration is that the aircrew must be able to disengage from the enemy fighters. In this mission it is not always easy to quit and go home as in the air-to-ground missions. Because of this, fuel is a frequent consideration which can cause an engagement to be avoided or limit the tactics of one once entered, such as little or no afterburner use.</p>

**Figure B-2 (Continued)**  
**Mission Requirements**

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.16 Egress	<p>2.16 Depart target area. This task includes all necessary evasion tactics required to avoid enemy defenses. Another requirement is to rejoin the flight members into formation. This task normally requires the airmen of each aircraft to visually locate each other and therefore weather and other visibility restrictions complicate the task. If returning from over enemy territory, then "safe-passage" procedures may be required. The airmen must rate route altitudes, and enemy defenses.</p> <p>2.16 Low: Depart target area in the same manner as penetration, (see 2.7a) except usually a different route is planned.</p> <p>High: Same as penetration (see 2.7c) except route and altitudes may vary.</p>	<p>2.16 Normally not required unless escorting other aircraft or involved in other operations over enemy territory. In these cases the altitudes are usually medium to high and rarely are low.</p>	

Figure B-2 (Continued)  
Mission Requirements

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.17 Cruise	2.17 Same as 2.2 except: More emphasis will be initially placed on system checks in order to detect damage or other problems. There will also be greater emphasis on planning the recovery particularly if the weather is marginal or a complicated approach must be flown. Alternate or emergency plans are formulated depending on existing conditions. The emphasis is on selecting the appropriate course of action prior to leaving cruise or holding conditions so that fuel consumption can be limited. This is the most comfortable and least demanding phase of flight and therefore provides the most time for in-flight planning.  (See Note 20)	2.17 Same as CAS  (See Note 20)	2.17 Same as CAS  (See Note 20)

## NOTE:

- (20) In order to accomplish worthwhile advanced planning in this phase of flight, the aircrew must have a wide variety of information available on the status of friendly airfields, such as the weather, navigation aids, approach procedures, etc. Much of the value of this information decays with time and therefore, is not useful if stored prior to flight. Other information frequently changes and therefore the data, must be formatted in such a way that it can be easily transmitted to the in-flight aircraft.

**Figure B-2 (Continued)**  
**Mission Requirements**

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.18 Air Refueling	2.18 Same as 2.4 except: This AAR is much more critical. If there are any errors in planning or estimating fuel use, distances, or times, then all aircraft on the mission could be lost. If the mission is terminated too soon, then the effectiveness may be less than desired. Getting enough fuel to get home will be a leading factor in the aircrew's decision making process.	2.18 (Optional. Same as CAS.)	2.18 Same as CAS. May require multiple AAR to maintain station time and combat fuel requirements.

**Figure B-2 (Continued)**  
**Mission Requirements**

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.19 Reengage	<p>2.19 Optional: Additional attacks after AAR may be possible depending on fuel, ordnance, position, and aircraft systems.)</p> <p>(See Note 21)</p> <p>2.20 Final decision as to base is made. Knowledge of field condition and alternates is needed. This task is also dependent on aircraft systems, fuel, distances to the airfield, and other operations which might affect landings. These should also be some concern for being able to "turn" the aircraft for additional missions.</p> <p>(See Note 22)</p>	<p>2.19 Not required.</p> <p>2.20 Same as CAS. If additional missions are flown from an alternate base, then consideration must be given for specialized flight planning aids the aircrew might require. This is over and above specialized munitions and AGE needed by the aircraft.</p> <p>(See Note 22)</p>	<p>2.19 Frequently required, but dependent on fuel, ordnance, crew fatigue, and aircraft systems.</p> <p>(See Note 21)</p> <p>2.20 Same as CAS. (See Note 22)</p>
2.20 Return to Base			<p>NOTES:</p> <p>(21) The ability to reengage in combat after a brief rest or replenishment of fuel is very valuable. This ability depends on having enough ordnance to still fight, but otherwise does not require ground facilities, maintenance, or additional ground related delays. If AAR is not available or possible, then aircraft designed to loiter longer with more ordnance are particularly attractive.</p> <p>(22) Even though this decision may have been made before flight or during cruise, there is always the possibility that an aircraft may have to divert at the last possible minute and under the worst of all possible circumstances. Information needs continue up to and through the final landing.</p>

**Figure B-2 (Continued  
Mission Requirements**

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.21 Descent	2.21 Requires planning to economically descend so as to arrive at a specific time and place. This can be required in a specified approach or in conjunction with an enroute radar descent. The key element is to save as much fuel as possible by trading altitude for airspeed and therefore increase range, endurance, or fuel reserve. If fuel is not a problem or is only a secondary consideration, then a speedy recovery is usually desired sequenced as necessary with other traffic.	2.21 Same as CAS.	2.21 Same as CAS.

Figure B-2 (Continued)  
Mission Requirements

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.22 Approach (All elements of aircraft maneuvering required or directed to align the aircraft with the landing runway.)	2.22 This task requires maneuvering via instruments or radar vectors to align the aircraft with the landing runway. It is also necessary to maintain safe separation from other aircraft operations, but interface in such a manner that delays are avoided.	2.22 Same as CAS.	2.22 Same as CAS.

**Figure B-2 (Continued)**  
**Mission Requirements**

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.23 Landing (Actions required to position aircraft safely on the runway.)	2.23 The final phase of flight that requires precise manipulation of flight trajectory onto the runway surface. It requires close adherence to airspeeds, angles of attack, rates of descent, and flight path along the ground. Smooth control is emphasized and sometimes unusual cross controlling techniques are required for a safe landing depending on winds, runway condition, or the approach to landing obstacles.	2.23 Same as CAS.	2.23 Same as CAS.

**Figure B-2 (Continued)**  
**Mission Requirements**

Mission Requirements  
Section 4 - Operations

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
3. Post Flight			
3.1	3.1 Maintenance crews safe remaining weapons and/or ejection cartridges and advise aircrew of safety status. If an aircraft cannot be "safer," it normally will be shut down in a safe area and will not be taxied among other aircraft. Other systems requiring dearming are flare and chaff ejectors or other explosive or highly combustible materials. Procedures and requirements differ for guns, rockets, missiles, bombs, etc.	3.1 Same as CAS.	3.1 Same as CAS.
3.2 Taxi	3.2 Same as 1.4.	3.2 Same as 1.4. (See Note 23)	3.1 Same as 1.4. (See Note 23)
3.3 System Checks	3.3		
	(a) Perform all aircrew systems checks or self-tests required to evaluate the aircraft's condition for the next mission. These checks emphasize the mission essential equipment.		
	(b) For broken equipment, the best diagnosis possible is required so that maintenance can understand and identify the problem.		
	(See Note 23)		

**NOTE:**  
 (23) Consistently one of the toughest problems in repairing complex aircraft equipment in routine training operations is the ability of the aircrew to convey to maintenance the problems encountered in flight. Forms and paperwork help, but slow operations, verbal debriefings are soon forgotten or are confused before they get to the person that does the work; self-test equipment fails or is engineered in such a way that it is not easily used. Clearly, there is room for improvement in this very important task.

**Figure B-2 (Continued)**  
**Mission Requirements**

PHASE	CLOSE AIR SUPPORT	AIR INTERDiction	COUNTER AIR
3.4 Shutdown	<p>3.4 Aircraft systems turned off and aircrew exit aircraft. All personnel equipment and aircraft provided debriefing aids, such as camera, magazines, are taken from the aircraft. Expended supplies, such as lunches and water bottles are also removed. These or similar tasks are frequently aircrew responsibilities and not those of maintenance.</p> <p>3.5 Post-Flight</p>	<p>3.4 Same as CAS.</p> <p>3.5 Same as CAS.</p>	<p>3.4 Same as CAS.</p> <p>3.5 Same as CAS.</p>

Figure B-2 (Continued)  
Mission Requirements

PHASE	CLOSE AIR SUPPORT	AIR INTERDiction	COUNTER AIR
3.6 Debrief	<p>3.6 Completion of all forms and documentation tasks required from the mission. The key element of this task is the ability to relay all useful information to maintenance, operations, intelligence, and higher headquarters functions. This information must be suitable for transmission and summarize significant observations and events that took place on the mission, such as damage assessment, enemy SAM's, troop concentration, tactics, ECM, etc.</p> <p>(See Note 23)</p>	<p>3.6 Same as CAS. (See Note 23)</p>	<p>3.6 Same as CAS. (See Note 23)</p>

**Figure B-2 (Concluded)  
Mission Requirements**

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